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<u>DISTRIBUTIONAL ANALYSIS OF POLLUTANT CONCENTRATIONS IN STORMWATER RUNOFF</u>

by

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ERRATA

Page 2, line 13, for "an yearly basis" read "a yearly basis".
Page 5, line 12, for "desirable" read "discernable".
Page 8, line 22, delete "basis".
Page 14, line 6, for "practitionners" read "practitioners".
Page 16, line 7, for "practises" read "practices".
Page 27, Table 1.9, for "V=SQR..." read "CV=SQR...".
Page 27, line 9, for "assumming" read "assuming".
Page 30, line 3, for "Then" read "Thus".
Page 38, line 14, for "steepest" read "steeper".
Page 42, line 8, for "sewage" read "sewerage".
Page 42, line 12, for "unconclusive" read "inconclusive".
Page 43, line 2, for "steam" read "stream".
Page 47, Table 2.2, insert value of "69" for NAP/NPP for AIX-NORD.
Page 56, line 5, for "concentrations" read "loadings".
Page 56, line 6, for "divided by the concentration time" read "over the time of concentration".
Page 59, line 21, for "Imax5 = maximum intensity..." read "Imax5 = maximum rainfall intensity".
Page 65, line 17, for "transfered" read "transferred".
Page 65, line 20, for "quantitiles" read "quantiles".
Page 69, line 21, for "transfered" read "transferred".
Page 82, line 1, for equation "$\beta_3 = N$..." read "$\beta_3 = N/[(N-1)(N-2)]$...".
Page 90, line 17, for "compromising" read "compromise".
Page 100, line 11, for "indices" read "parameters".
Page 107, line 23, for "the maximum" read "The maximum".
Page 108, line 6, for "can no longer" read "cannot".
Page 119, line 8, for "modelisation" read "modelling".
Page 119, line 22, for "hypothesis" read "hypotheses".
Page 122, Table 5.2, for "Desbordes et. al." read "Desbordes and Servat".
Page 125, line 27, for "linear variable" read "EV variable".
Page 130, line 5, for "Office" read "Organisation".
Page 130, line 10, insert "Kite, G.W. (1975). Confidence Limits for Design Events. Water Resources Research, vol.11, No1, pp.48-53."
Page 169, line 9, for "computing program" read "computer program".

PREFACE

1. The Urban Pollution Research Centre was established in 1976 with the purpose of investigating problems of urban stormwater pollution within catchments in North West London. This aim has been extended to the investigation of water and atmospheric quality problems and management within urban areas generally and to educational objectives of postgraduate student training.

2. Existing members of the Research Centre are:

Academic Staff	Research Assistants/Students	
Professor J B Ellis	Miss T A Mansfield	SERC
Dr R Hamilton	Mr I S McCrae	SERC
Dr D M Revitt	Mr A D Bascombe	SERC
Mr R B E Shutes	Mr N Tranter	SERC
Mr C Abbess	Mr M Brizio	EC
Professor M J Hall	Mr A Ojolo	
	Mr P Beckwith	
	Mr J Nolan	

Research Fellows

Dr M A House

Dr G M P Morrison

Technical Staff

Chief Technician:	Mr G S Morris
Research Technician:	Mr A J LaGrue

3. Current research topics being undertaken by the Research Centre, with source of support include:

Heavy Metal Speciation in Urban Drainage Systems. Hydrocarbons in Receiving Water Sediments. British Council/EEC.

Modelling Procedures for Evaluation of Receiving Water Impacts from Urban Runoff. EWPCA/OECD/Sir William Halcrow & Partners for NWWA/Binnie & Partners for HR Ltd.

Design and Operation of Flood Storage Ponds. CIRIA/Hartsmere Borough Council.

Pollution Biomonitoring of Urban Runoff. SERC/WRc/NAB.

Surface Water Quality Classification and Catchment Management. NAB/WRc/NWWA.

Heavy Metals in Urban Surface Dust. SERC/London Scientific Services.

Aerosol Analysis and Soiling Potential. SERC/London Scientific Services.

Dispersion of Traffic Related Pollutants. SERC/TRRL.

Population Exposure to Heavy Metals and Hydrocarbons. British Council.

Receiving Water Impacts Resulting from Remobilisation of Sewer Overflow Sediments. SERC/WRc/TWA.

Storm Flow and Quality Routing through an Urbanising Catchment. SERC/TWA/Local Authority.

Post-Project Appraisal of the Detention Efficiency of Storm Retention Tanks. CIRIA/TWA/NCC.

Urban Water Quality Catchment Monitoring. Chinese Environmental Protection Board/Chinese Academy of Environmental Sciences.

4. Research Reports of the Pollution Centre include:

- No. 1 Review, Objectives and Preliminary Considerations. J B Ellis.
- No. 2 Urban Stormwater: Macroinvertebrate Biology and Bacteriology. R B E Shutes & J B Ellis.
- No. 3 Urban Stormwater: Water Quality Baseline Data. J B Ellis.
- No. 4 Water Quality Indices: A Management Tool. M A House.
- No. 5 The Selection of Determinands for Water Quality Classification. M A House.
- No. 6 Stormwater Pollution of Highway Surfaces: A Review. O Harrop.
- No. 7 Instrumentation and Method in Stormwater Monitoring. O Harrop.
- No. 8 Heavy Metal Speciation Studies of Natural Waters: A Review. G M P Morrison.
- No. 9 The Development of Rating Curves for Water Quality Clasification. M A House.
- No. 10 Traffic Related Pollutants, their Effects and Analytical Assessment Techniques. I S McCrae.
- No. 11 Biological Monitoring of Benthic Invertebrates for the Assessment of Heavy Metal Pollution in Urban Rivers. A D Bascombe.

ABSTRACT

A distributional analysis has been undertaken of the event mean concentrations (EMCs) of pollutants discharged during storm events from separately sewered stormwater drainage systems in four representative French urban catchments. Six basic distributions have been tested following a review of both the literature and of actual fitting procedures which demonstrated that stormwater EMCs appear to conform to a lognormal distribution. A BASIC program compatible for IBM PC use has been developed and the goodness of fit evaluated for COD, BOD_5, TSS, Zn^{2+}, NO_3^- and N-NH_4^+, in respect of two sets of urban catchments located in the Paris and Aix-en-Provence regions respectively.

The optimum fits are provided by maximum likelihood methods with three of the tested distributions possessing broadly similar fitting performances:

- the three parameter lognormal distribution;
- the Fréchet (Extreme Value type 2) distribution;
- the two parameter lognormal distribution.

These three distributions showed best fits for TSS and COD EMCs.

A stepwise regression analysis has also been undertaken to provide a regional differentiation of the pollution parameters based on lumped hydrological and storm event characteristics. Although the resultant multiple correlation coefficients are relatively weak, the main explanatory variables confirm the significance of peak flow rates and rainfall intensity in driving the stormwater flow quality within the sewer system, especially in the case of the southern Mediterranean catchments. Antecedent dry period is only of significance in the northern Parisian catchments.

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CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1 Context and objectives of the Research

During the last ten years, the problem of water-course pollution in the UK and within Europe generally has become an increasing cause for concern. The Scottish Development Department (1977) originally highlighted the deleterious effects of many storm sewage overflows on receiving watercourse quality and more recently Aspinwall and Ellis (1986) have described some impacts of both combined sewer overflows (CSO) and urban stormwater runoff on river quality in terms of the pollutant load. Strong impairments of river quality objectives due to both short-term (acute) and long-term effects were presented.

During the early seventies, computer simulation was introduced to describe runoff phenomena from urban areas during a storm event. Today, reasonably accurate predictions of the volumetric discharge of a stormwater drainage system can be made for varying time periods through a storm event. Similar techniques applied to the simulation of pollutant transport have not been so successful. One must admit that such processes are the product of a random variability which does not readily allow deterministic relations to be worked out easily. Data bases of pollutants in urban runoff exhibit a high degree of variability, which is typical for all discharge sources generated by rainfall-runoff processes on impermeable surfaces. A probabilistic modelling approach would appear to be particularly suitable to deal with this natural variability.

The storm event has been adopted as the basic unit of measurement, because knowledge of within-event pollutant concentration variability provides little useful information for the decision maker in terms of appropriate control measures. Therefore, in this study, individual storm events are characterised by the "Event Mean Concentration" (EMC) of each of the described pollutants.

The EMC is defined as the concentration that would result if the entire storm event discharge were collected in a container, and its concentration determined. It can also be defined as the total mass of pollutant discharged during the event divided by the total quantity of water discharged during the event.

Acute effects of pollutants can be assessed on the basis of EMCs: the discharge of biological oxygen demand (BOD) causes oxygen depletion during the event and the discharge of acute toxicants can damage the fish population almost instantaneously. The discharge of nutrients or heavy metals, on the other hand, leads to accumulation in the receiving water environment and causes problems only when critical levels have been reached: such processes are considered to be long-term or accumulative effects judged on an yearly basis.

Both acute and accumulative effects have to be considered on the basis of statistical distributions in order to work out the return period of an EMC or a pollutant load. For example the concentration corresponding to a 10 year return period means that, on average this concentration will be exceeded once every ten years. As Section 1.4 will argue, a review of the fitting procedures applied to runoff or combined sewer overflow (CSO) discharges clearly demonstrates the value of the lognormal distribution as an appropriate and simple tool to analyse the variability of stormwater pollutants. A very powerful property of this distribution is that any linear combination of variables which follow the lognormal distribution will approximately follow a lognormal distribution. This property has already been used to estimate the return period of the concentration of pollutants within a receiving stream fed by stormwater discharges (US EPA, 1984). However, a number of methodological questions remain unresolved including the universality of the procedure for both separate and combined systems as well as for differing catchment and storm event characteristics. The appropriateness of the lognormal distribution in terms of sensitivity and goodness of fit also needs thorough testing if it is to be used for reliable forecasting.

The purpose of this research project has been to evaluate the distributional properties of EMC data in relation to transient and short-term changes in river quality due to storm events. In less general terms, the immediate aims of the study are:

(a) To select from amongst six statistical distributions, the best one to fit data sets of pollutant parameters based on four separately sewered catchments chosen as test catchments during the French National Programme (1980-1982).

The six distributions to be tested are widely used in hydrology. They are the two parameter lognormal distribution, the three parameter lognormal distribution, the General Extreme Value Type 1 (Gumbel) and Type 2 (Fréchet), the Pearson Type 3 (3 parameters) and the gamma distributions. The goodness of fit is assessed graphically as well as analytically for both the method of moments and the method of maximum likelihood. The BASIC program and the fitting procedures are described in Chapter 3 whereas the results are presented in Chapter 4. Six sets of stormwater quality data, which formed the basis of data collected in the four French catchments, are used here ie. COD, BOD_5, TSS, NO_3^-, $N\text{-}NH_4^+$, Zn^{2+}. General comments about this data set are given in Chapter 2. It must be emphasised here that an independent and original BASIC program has been developed for this research, because no available statistical package provided the appropriate answers to our specific working objectives. Packages such as Minitab, SPSSX, GLIM, MLP and Statgrafics do not offer the range of distributions that have been chosen to be tested.

(b) Calibration and correlation of the pollution parameters EMCs against lumped hydrological characteristics such as antecedent dry period duration, rainfall volume, rainfall intensity, etc., are undertaken to derive regionalisation factors for use in forecasting methods. Chapter 5 presents the procedure and the results of this regionalisation work involving a stepwise regression analysis.

The outcome of this research is intended to provide a further contribution towards answering the question of which statistical distribution is best suited to stormwater quality data sets. Such a distribution will firstly provide a reliable return period for an EMC and secondly be used in a mass balance approach which would provide the return period of a given concentration within the receiving stream.

1.2 The Water Quality Runoff Data Bases

1.2.1 The European Urban Runoff Data Base

Table 1.1 lists flow weighted average concentrations (EMCs) and loadings for urban runoff that have been reported to the European Water Pollution Control Association (EWPCA) Urban Runoff Quality Committee (1987). Nine countries from the western part of Europe have reported work in the field of urban runoff showing that concern is growing. Nevertheless there is a need for more catchment data covering various characteristics involving sediment properties, etc. which need to be further investigated.

Evaluation of the data shows that, whilst pollution concentrations and loadings vary between different urban areas and sewer type without any readily desirable causative factors, there can be no doubt that urban storm runoff can be highly polluted and is at best equivalent to secondary effluent quality. Although it may have limited value as a statistic, the average runoff concentration is reported consistently and can be used to illustrate the inherent variability in reported data. Mass loadings also enable different sized catchments to be compared. This statistic also displays a high degree of variability between areas, with the possible exception of metals, which are reasonably consistent for the limited data base available.

Individual studies of pollutant sources and types, washoff transport processes, outfall/catchment loadings and receiving stream impacts have been reported from most European countries but there have been few if any attempts to provide co-ordinated or consistent data bases similar to those established under the US EPA Nationwide Urban Runoff Program (1983). The development of appropriate analytical methodologies for the modelling and assessment of receiving stream impacts of intermittent urban runoff have likewise been slow in comparison to the United States where a variety of urban runoff quality simulation models have been available for some time.

EWPCA (1987).

Flow weighted average concentrations (mg l^{-1}) and loadings(kg ha^{-1} yr^{-1}); bacterial counts (MPN/100 ml)

Location, Author/Source	Sewer Type	Slope %	Area (ha)	Imp. %	Pop. (p/ha)	Events/Obs. (No.)	Concentrations (Mg l^{-1})									Loadings (kg ha^{-1} yr^{-1})							
							SS	BOD	COD	NO_3-N	N_{tot}	P_{tot}	Pb	Zn	Faecal Coliforms	SS	BOD	COD	NO_3-N	N_{tot}	P_{tot}	Pb	Zn
FINLAND																							
Pakila, Helsinki (Melanen)	S	20	20	29	30	13 - 56	220	12	93		1.6	0.25	0.09	0.14		22	1.5	11.0		0.25	0.03	0.01	
Kaukovainio, Oulu (Melanen)	S	0.5	41	30	85	19 - 57	160	14	120		1.7	0.27	0.13	0.34		8.7	1.3	11.0		0.20	0.03	0.01	
Hameenpuisto, Tampere (Melanen)	S	1.4	13	67	125	36 - 63	270	28	140		2.2	0.43	0.43	0.45		120	10.0	54.0		0.95	0.19	0.16	
NORWAY																							
Ova, Trondheim 1. (Lindholm)	C	1.1	21	37	93	13	510		352			3.0				1573		1088					
Risvollan, Trondeim 2. (Lindholm)	S	5.3	20	18	30	14	929		74		2.3	0.3	0.07	0.10		160		127			0.5	0.12	0.50
Bistettbekken, Oslo 1. (Lindholm)	C	2.8	219	69	342	18	721	200	530		8.2	2.4	0.45	1.07		1867	518	1373					
Oslo 3. (Lindholm)	S		37	43	155	9	367		73		4.9	0.5	0.10	0.17		628		125			0.8	0.17	0.29
Vestli, Oslo 4. (Lindholm)	S	9.3	37	33	123	11	86		63		5.9	0.8	0.05	0.32		164		120			1.6	0.10	0.61
Rukklabekken, Sandefjord (Lindholm)	C	2.5	380	12	25	9	424	103	268		14.4	4.0	0.08	0.64		537	131	340				0.83	6.61
SWEDEN																							
Mellbyleden, Goteborg (Malmquist)	S		15.6	39	115	7	79		89	1.2	2.5	0.21	0.16	0.33	2100	52		60			0.17	0.12	0.27
Veyagaten, Goteborg (Malmquist)	S		5.8	53	250	9	140		120			0.33	0.39	0.44	600	101		138			0.41	0.45	0.63
Bergsjosvangen, Goteborg (Malmquist)	S		4.8	45	85	6	67		69	1.3	2.4	0.20	0.20	0.24	790	83		85			0.38	0.15	0.24
Linnegatan, Malmo (Hogland)	C	0.5	250	25	50	103 (Ob)	180	53	460		7.6	1.80	0.10	0.32	$0.1x10^6$								
DENMARK																							
Cedervaenget, Lyngby (Harremoes)	C	1.1	5.3	45	94	23 - 30	155	30	138	2.1	9.2	2.6	0.11	0.52									
Vestre Paradisvej, Soelleroed (Harremoes)	C	1.1	17.2	23	21	20 - 28	197	31	121	0.6	9.4	2.6	0.15	0.30									
Munkerisparken, Birkeroed (Harremoes)	C	0.8	6.4	46	27	19 - 36	52	4.4	37	1.2	1.4	0.11	0.04	0.34	3200								
Soender Ege, Ry (Simonsen)	C		45	-	-	34			20		5.3	1.7											
Noerremarken, Viborg, (Simonsen)	S		159	-	-	-	90		11		5.8	0.38	0.09	0.30									
Skvaetmoelle, Skanderborg (Simonsen)	S		27	-	-	5 - 27	354		15		2.9	0.86	0.02										
Ladegaardsbakken, Skanderborg (Simonsen)	S		7.5	-	-	5	241		31		6.7	0.68	0.05	0.04									
Aalborg Oest (Hvitved Jacobsen)	S		8.8	-	-	12	15						0.10	0.45									
NETHERLANDS																							
Bastion, Lelystad (Uunk)	S	0.1	4.5	66	150	8	142	7	58	3.3	4.1	0.75	0.10	0.74	3000		6.9			6.0	0.34		
Heerhugowaard (Uunk)	S		12.5	-	-	-	36	25	35		2.2	0.32	0.01	0.09									
FRG																							
Pullach II, Munchen (Brunner)	S	0.7	23	35.6	35	40	158	11	90	1.01	3.78	1.6				232	40	142	1.8	-	1.8		
Harlaching, Munchen (Geiger)	C	0.1	528	40	200	600/2000 (Ob)	153	102	275		21.0	8.4				1312	784	1943		151.0	67.0		
Busnau, Stuttgart (Krauth)	S	0.6	31.7	38	125	-	177	114	88		19.4	6.6				1426	919	846		156.0	53.0		
Emil Clar Strasse, Frankfurt (Gniosdorsch)	C	0.1	70.3	82	-	24	422	180	126	6.6	21.1	9.5											
Lettigkautweg, Frankfurt (Gniosdorsch)	C		45.3	31	-	18	463	180	108	3.2	23.7	15.2											
Westhausen, Frankfurt (Gniosdorsch)	S	0.1	88.6	48	-	12	515	46	81	9.7	12.2	1.2											
Sammler, Hurth (Pecher)	C		504	42	-	4	681	58	138	2.2		17.5		0.37									
Rubgarten, Gniebel	C	0.4	35	50	-	56	586	60	130	2.4	3.6	1.4											
SWITZERLAND																							
Schwamendingen, Zurich (Roberts)	C	0.5	9	47	200	90	83	8	37	1.0	2.1	0.18	0.11	0.13		314	30	138	3.7		0.7	0.42	0.05
Kanalisation Friedacker, Zurich, (Dauber)	C	5.0	12.7	42	129	-	212	109	498	0.11	40.6	13.1	0.02	0.28		87	63					0.04	
FRANCE																							
Maurepas, Paris (Deutsch)	S	0.5	26.7	60	100	174	191	12	77	6.1						940	55	380	23.0	26.0	4.1	0.41	1.65
Les Ulis, Paris (Deutsch)	S	0.6	43.1	42	350	97	439	34	108	7.8		1.32	0.28	0.64		1100	85	460	14.0	16.0	4.9	0.30	0.86
Aix Zup, Aix-en-Provence (Deutsch)	S	2.9	25.6	78	210	75	296	38	202	9.8		3.20	0.34	0.89		630	75	430	11.0	12.0	2.6	0.35	0.66
Aix Nord, Aix-en-Provence (Deutsch)	S	6.5	92.0	35	40	73	473	45	278			1.75	0.02	0.14		300	30	160	2.0	3.4	0.65	0.17	0.23
UK																							
Chelmsly Wood, Birmingham (WRc)	S		107	35	107	-	130	14	134		0.5	0.21	0.34	0.39		225	28	234			0.36	0.59	0.68
St Andrews, Northampton (HMSO)	C		93	50	102	-	370	95								2459	672						
Coopers Lane, Bradford (Gameson)	C		68	28	90	-	237	43								308	126						
Rastrick, Brighouse (Gameson)	C		240	11	15	-	647	86								154	61						
Shephall, Stevenage (Mance)	S		143	23	66	80	112			1.7	2.0		0.21	0.27		101							
Clifton Grove, Nottingham (Pratt)	S	3.0	10.6	42	85	18	21	7	39		8.8											0.23	0.45
Graham Park, N London (Ellis)	S	1.8	350	39	34	18	516	22	165	2.3	6.5	0.72	0.40	0.67	4865	184	32	210	4.2	18.5	0.84	0.27	0.73
Oxhey, N London (Wilkinson)	S	2.2	247	18	51	79	194	7								69	11.0						
Oxhey, N London (Ellis)	S	2.2	247	20	64	24	194	31		1.3	2.4	0.37	0.39	0.30	3840	190	47					0.38	0.45
Untreated Storm Sewage Wastewater							484	75	383		40.0	10.0			$0.9x10^7$	87	36	270		2.0	0.25	0.11	0.30
																3262	920	2685		20.8	1.90	1.6	5.33

1.2.1.1 The European EMC Data

The EMC data base for the various European experimental catchments presented in Table 1.1 includes data from the four French catchments investigated in the present study.

The EMC (event mean concentration) is defined by the following formula:

$$EMC = \frac{\text{Mass of Pollutant discharged during the event}}{\text{Quantity of water discharged during the event}}$$

or with discrete measurements:

$$EMC = \frac{\sum_{i=1}^{N-1} [\ C_{j,\ i} . Q_i + C_{j,\ i+1} . Q_{i+1}\ ]\ .\ \Delta t/2}{\sum_{i=1}^{N-1} [\ Q_i + Q_{i+1}\ ]\ .\ \Delta t/2}$$

with $C_{j,\ i}$ = "instantaneous" sample concentration for time i and pollution parameter j;

Q_i = "instantaneous" discharge at time i;

Δt = time between samples;

N = number of ordinates.

As reported by EWPCA (1987), "the availability of a large population of EMCs can provide a degree of reliability to any derived statistical measures or distributional analysis, and also offers a number of other additional advantages:

- provides concise summaries of what is inherently variable data;

- provides a more useful method of reporting data than the use of ranges;

- enables comparison of results from different sites, events conditions etc., to be conveniently made;

- provides a convenient quantitative framework for examining the transferability of data;

- the use of a "constant" concentration value for a particular sewer type, land use, hydrology etc., in conjunction with an accurate hydraulic analysis, can provide a very useful load estimation;

- can be used to compute loading on the annual timescale associated with long term receiving water quality impacts".

The EMC values associated with hydrological catchment and sewer data provide an appropriate characterisation of urban runoff quality.

1.2.2 The American Urban Runoff Data Base

During the Nationwide Urban Runoff Program (NURP) launched by the US Environmental Protection Agency (1983), data were collected by 31 nationwide projects. Figure 1.1 shows the locations of those study areas.

As presented in Terstriep et. al. (1986), over the 31 projects, 19 were undertaken with little or no participation of the US Geological Survey . There were 237 catchments (sampling stations) related to those 19 projects for which 588,650 rainfall and runoff observations were recorded and 102,720 samples including in-stream data, atmospheric dust and street dirt samples were analysed. The majority of the samples for water quality analysis basis were flow-weighted composite samples although a few discrete samples collected through the course of the events are available. The raw data from non-USGS data have been stored in the USEPA STORET Data Base which provides fixed site data as well as measurement data.

The fast track data base compiled the information of all sites in terms of EMC. In order to evaluate whether or not a real problem (with a manageable solution) existed on a national scale, the information corresponding to twelve pollutants was included in this data base. The pollutants were: TSS, COD, BOD_5, Cu, Pb, Zn, total coliforms, faecal coliforms, Ptot., Psol., TKN, total nitrate + nitrogen.

A lot of work has already been done upon this plentiful and positive data base in terms of statistical and physical modelling. A good review of this work can be obtained in papers included in the proceedings of an Engineering Foundation Conference (1986) whereas various reports corresponding to local sites can be obtained from local authorities in the US. Final reports on the results of the NURP have been published by US EPA (1983).

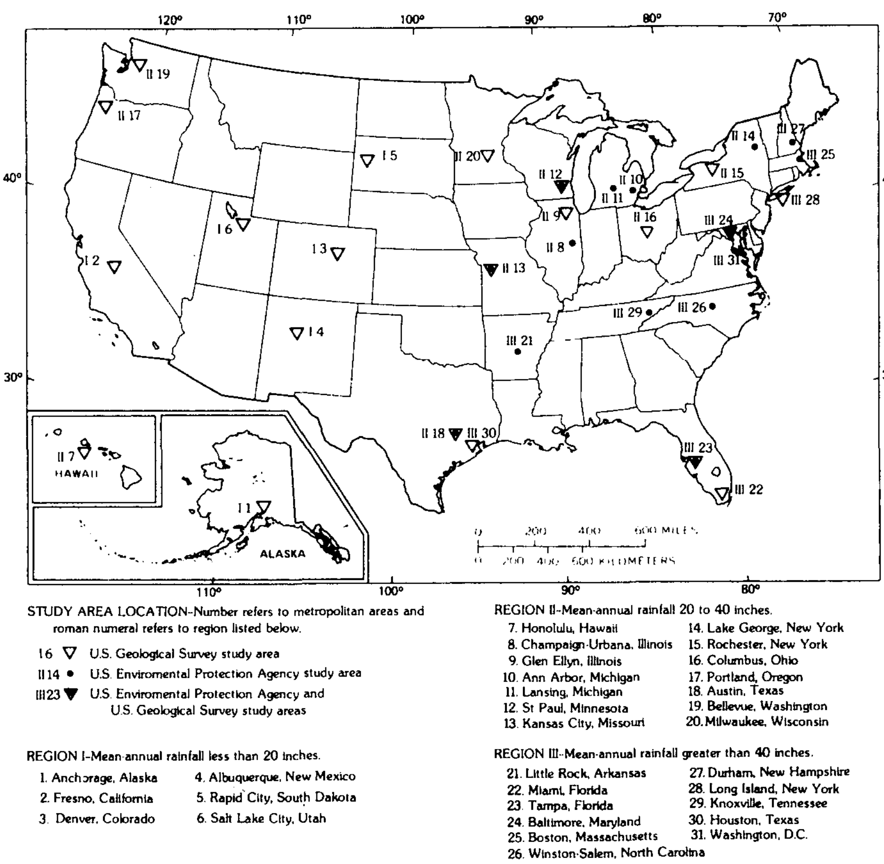


Figure 1.1. Locations of urban-stormater study areas and mean-annual rainfall regions in the US. After Driver et. al. (1986).

1.3 Characteristics of Urban Runoff

1.3.1 General Statistics of Urban Runoff

Urban runoff quality is affected by the combination of many non-point, diffuse sources since rainfall, runoff and pollutant concentrations vary in space and time. The effects of this combination are a high variability of runoff quality within and between events, as well as from site to site. The discharge of pollutant loadings is usually of relatively short duration in comparison with the time separating events. Table 1.2 illustrates this fact by showing average values for several catchments in the United States.

Table 1.2. Average storm duration and time between storms for selected locations in the United States. After Mancini et. al. (1986).

Location		Average Annual Values in Hours	
		Storm Duration	Time Between Storm Midpoints
Atlanta, GA		8.0	94
Birmingham, AL		7.2	85
Boston, MA		6.1	68
Caribou, ME		5.8	55
Champaign-Urbana, IL		6.1	80
Chicago, IL		5.7	72
Columbia, SC		4.5	68
Davenport, IA		6.6	98
Detroit, MI		4.4	57
Gainesville, FL		7.6	106
Greensboro, SC		5.0	70
Kingston, NY		7.0	80
Louisville, KY		6.7	76
Memphis, TN		6.9	89
Mineola, NY		5.8	89
Minneapolis, MN		6.0	87
New Orleans, LA		6.9	89
New York City, NY		6.7	77
Steubenville, OH		7.0	79
Tampa, FL		3.6	93
Toledo, OH		5.0	62
Washington, DC		5.9	80
Zanesville, OH		6.1	77
	Mean[1]	6.1	81
Denver, CO		9.1	144
Oakland CA		4.3	320
Phoenix, AZ		3.2	286
Rapid City SD		8.0	127
Salt Lake City, UT		7.8	133
	Mean	6.5	202
Portland, OR		15.5	83
Seattle, WA		21.5	101
	Mean	18.5	92

Note: Typical values.

	Average hours	90% hours
Storm duration	6	15
Interval between storm midpoints	80	200

In terms of EMC, typical figures illustrating site-to-site variations and event-to-event variations at a site are presented in Table 1.3.

Table 1.3 Water quality characteristics of urban runoff in the US. After Mancini et. al.(1986).

Constituent	Event-to-Event Variability in EMCs (Coef Var)	Site Median EMC For Median Urban site	Site Median EMC For 90th Percentile Urban site
TSS (mg/l)	1-2	100	300
BOD (mg/l)	0.5-1.0	9	15
COD (mg/l)	0.5-1.0	65	140
Total P (mg/l)	0.5-1.0	0.33	0.70
Solid P (mg/l)	0.5-1.0	0.12	0.21
TKN (mg/l)	0.5-1.0	1.50	3.30
NO_{2+3}-N (mg/l)	0.5-1.0	0.68	1.75
Total Cu (ug/l)	0.5-1.0	34	93
Total Pb (ug/l)	0.5-1.0	144	350
Total Zn (ug/l)	0.5-1.0	160	500

The coefficient of variation (standard deviation/mean) varies according to the type of catchment. Figures 1.2 to 1.7 show the results (US EPA, 1983) based on 37 low density residential sites, 3 high density residential sites, 10 commercial sites and 2 industrial sites. In the paper by Terstriep et. al. (1986), it has been indicated that for low density residential sites, the coefficient of variation ranges between 0.45 and 0.61 for BOD_5, COD, Ptot. and TKN whereas it varies between 1.09 and 1.53 for TSS, NO_{2+3}, Cu and Zn. For the commercial sites, the coefficient of variation is lower with Psol. and Zn being at 0.75 and 0.86 respectively whereas for the remaining pollutants it ranges between 0.22 and 0.60. For all the pollutants presented except the TSS, the high density residential sites seem to be more polluting than the other types of site.

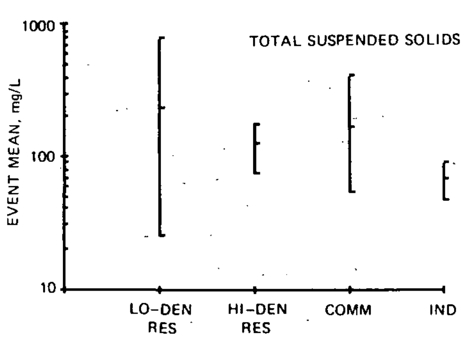


Figure 1.2. Maximum, minimum and mean concentrations of TSS. After Terstriep et. al. (1986).

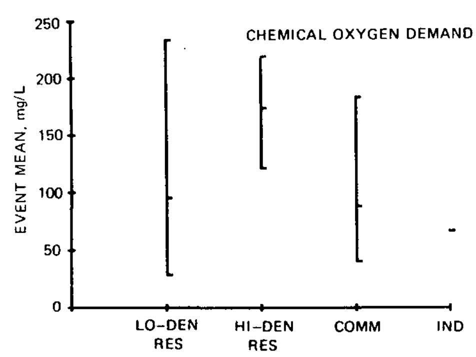


Figure 1.3. Maximum, Minimum and mean concentrations of COD. After Terstriep et. al. (1986).

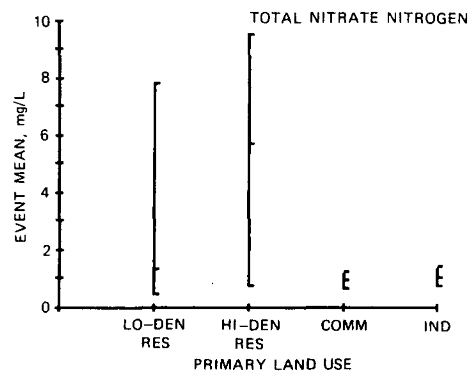


Figure 1.4. Maximum, minimum and mean concentrations of total nitrate nitrogen. After Terstriep et. al. (1986).

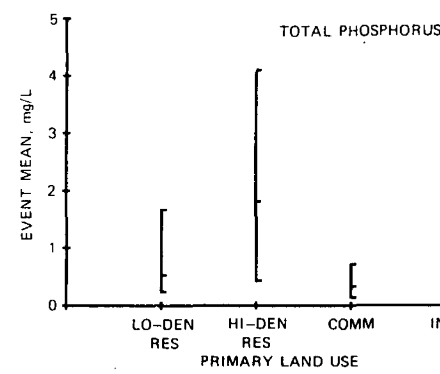


Figure 1.5. Maximum, minimum and mean concentrations of total phosphorus. After Terstriep et. al. (1986).

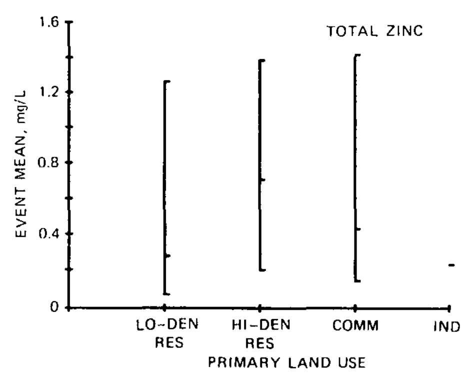


Figure 1.6. Maximum, minimum and mean concentrations of total zinc. After Terstriep et. al. (1986).

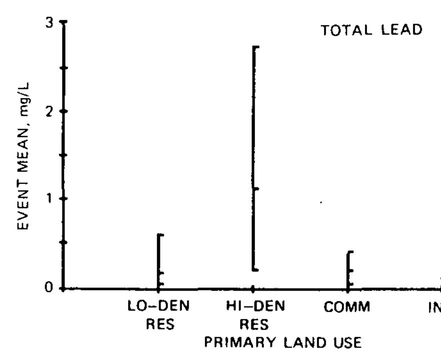


Figure 1.7. Maximum, minimum and mean concentrations of total lead. After Terstriep et. al. (1986).

The stormwater quality and the loads carried during an event are also highly influenced by the climatic conditions before and during the event. Ellis et. al. (1985) have shown, through stepwise regression analysis, that climatic parameters such as the total rainfall volume, the maximum 5-minute duration rainfall intensity, the storm duration, the antecedent dry period length or the total surface discharge are highly correlated with pollutant loads from highway runoff. The combination of three of these parameters can explain from 70% to 99% of the variance of the polluting loads for TSS, Pb, Cd, Fe, Zn, and Cu in the particular example presented.

The range of average EMCs for Europe are displayed in Table 1.4, which has been prepared from Table 1.2. Those ranges are very similar to those measured in the United States and displayed over Figures 1.2 to 1.7.

Table 1.4. Range of average (site-to-site) EMCs for separate drainage systems in Europe.

Pollutant Indicator	Range of average EMCs for separate systems in Europe (mg/l)
TSS	15 - 930
BOD	4 - 45
COD	11 - 280
$N\text{-}NO_3^-$	0.6 - 10
Ptot.	0.1 - 3.2
Zn	0.04 - 0.9

An overview of the polluting potential of stormwater runoff is given in Table 1.5 where typical EMCs for urban runoff and typical concentrations of domestic wastewater after secondary treatment are given. Table 1.5 also shows that in terms of TSS and Zn, stormwater is, on average, more polluted than treated wastewater whereas COD concentrations are roughly comparable.

Table 1.5. Comparison of waste quality parameters in urban runoff with domestic wastewater (mg/l). After Bastian (1986).

pollutant	Typical EMC concentration for Urban Runoff (mg/l)	Typical concentrations for Domestic wastewater (mg/l)	
		before secondary treatment	after treatment
TSS	150	220	20
COD	75	500	80
Ntot.	2	40	30
Ptot.	0.36	8	2
Zn	0.2	0.28	0.08

1.3.2 **Within-Event Characteristics**

The mechanisms involved in urban runoff quality during a storm event are, as described previously, highly variable in nature as well as complex in form. However some basic patterns can be identified.

The 'first-flush' phenomenon is now well recognised by stormwater practitionners for both separate and combined systems (Thornton et. al., 1987). This process occurs when in-pipe pollutants and deposits are removed early in the storm event, showing a pollutant peak preceding the flow peak. Revitt et. al. (1986) have shown that soluble components can be washed through the system very early in the storm whereas the delivery of solids and their associated pollutants is dependent on re-suspension of in-pipe sediments. The temporal variation in the TSS pollutograph is of particular importance for controlling the behaviour of correlated pollutants such as BOD_5, COD and lead, the latter having a high affinity with the particulate phase. BOD, COD and TSS have also been found to be highly correlated within an event. It has also been shown that maximum TSS concentrations within an event can be linked with the maximum flow of the hydrograph. This tendency seems to be well marked for the highest maximum flows (Ministère de l'Urbanisme, du Logement et du Transport, 1985).

Figure 1.8 from the Maurepas catchment displays both BOD_5 pollutograph and hydrograph for the event No. 3 recorded during the French National Programme. This graph shows the first flush concentration peak as well as the peak corresponding to the maximum flow.

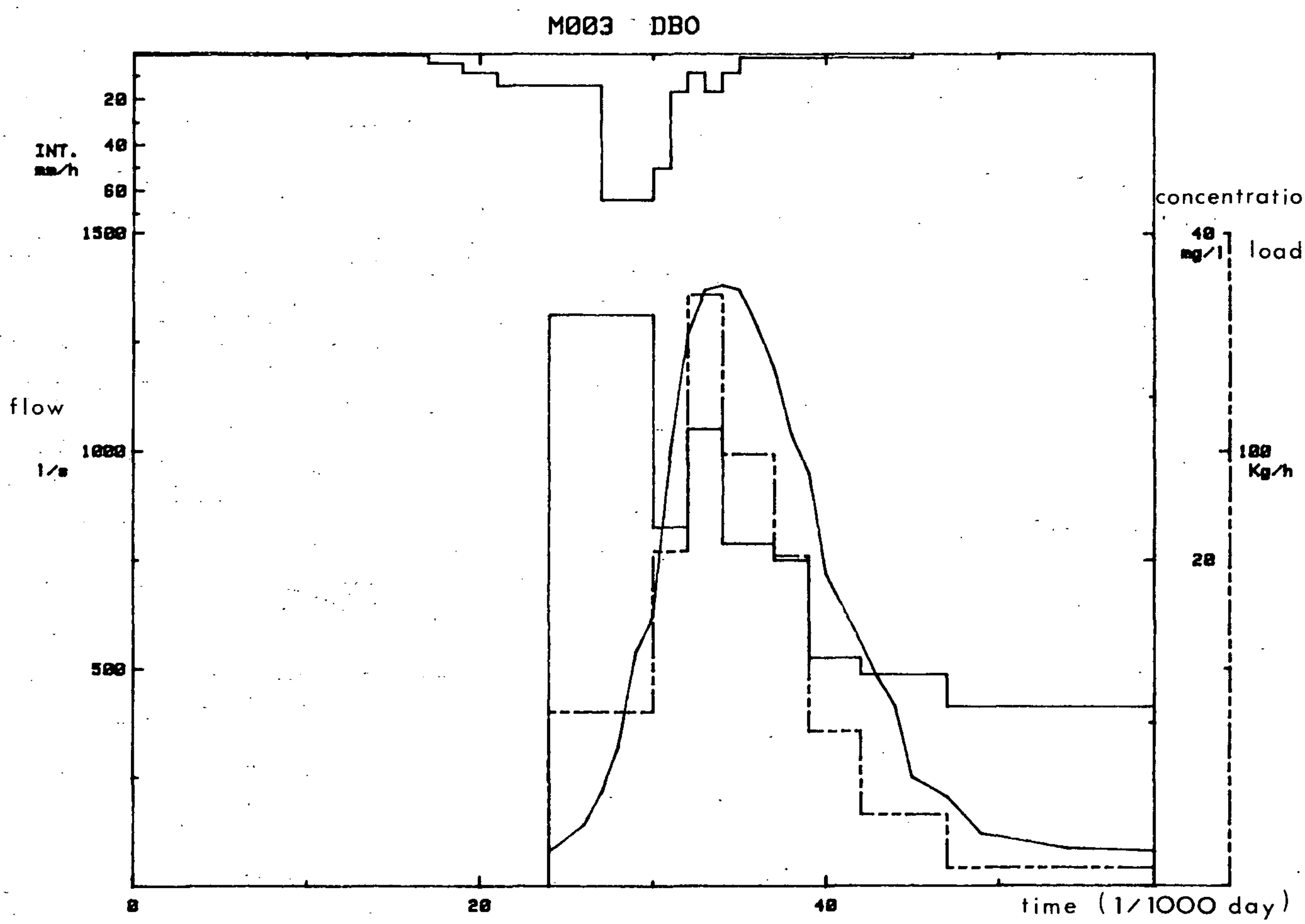


Figure 1.8. BOD_5 pollutograph and hydrograph at the Maurepas catchment, France. After Hémain (report LHM 25/1983, 1983).

1.4 The Effects of Stormwater Runoff on Receiving Streams

The impacts of urban runoff upon a receiving body can be different for each individual case considered. They depend mainly on:

- the nature and concentration of the pollutants involved;

- the nature of the receiving body and its hydrological, biological and chemical characteristics;

- The activities and practises undertaken in the water body eg. water supply, fishing, bathing, etc.

Pollution problems from urban runoff are generally divided into two categories depending on their time-based effect, (Harremoës, 1982; US EPA, 1983; Hvitved-Jacobsen, 1986): short-term (acute) and long-term effects. When the water body threshold of tolerance is reached because of the effect of intermittent runoff loads discharged, then acute impacts appear. The nature and time scales of urban runoff impacts on receiving water quality are illustrated in Figure 1.9.

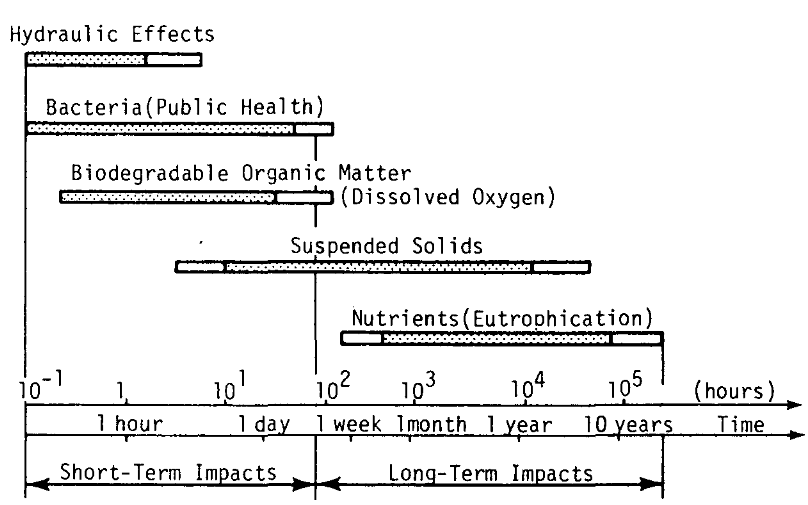


Figure 1.9 Time scales of urban runoff pollution impacts on receiving waters. After Driscoll and Mancini (1978).

1.4.1. The Short-Term Impacts

Short-term effects are characterised as discrete events in terms of identifying the duration of their impact which, ideally, has no overlap from one event to the next.

The impact caused by specific pollutants lasts as long as the duration of the event but the damage to the biology and fish population may extend beyond the duration of the event. The first flush phenomenon described earlier may result in localized drastic effects such as fish kills and high turbidity. Villeneuve and Lavallee (1986), in assessing the impact of combined sewer overflows, reported that sediments immediately downstream of outfalls were 10-50 times more contaminated than those upstream. It was concluded that instream pollutant concentrations downstream of outfalls increased during wet weather by as much as 2-7 times above the dry weather levels. The recovery period was found to be 48 hours for most parameters. It must be noticed that resuspension of pre-existing pollutants during a storm event is likely to be responsible for this impairment of the receiving stream water quality. Released toxicity of deposited heavy metals, high turbidity or dissolved oxygen (DO) depletion are usually side effects of the resuspension phenomenon.

In the particular case of metal toxicity, the sensitivity of aquatic organisms is highly variable depending on the chemical parameters of the receiving water, the metal considered, the aquatic species being considered and their life stage. Table 1.6 illustrates the effect of hardness and alkalinity on the acute toxicity of zinc to rainbow trout. The term 96 hr LC50 is the lethal concentration for which 50% of the fish population will die over 96 hours (4 days) under laboratory conditions. Table 1.7 shows the acute toxicity of zinc to rainbow trout.

Table 1.6. Effect of hardness and alkalinity on the acute toxicity of zinc to rainbow trout of similar size (a).

Hardness mg/l	Alkalinity mg/l	96 hr LC50 mg/l
315	227	7.21
102	81	1.00
23	20	0.56

[a]Goettl et al. 1971.

Table 1.7. Effect of fish size on the acute toxicity of zinc to rainbow trout in hard water at a temperature of 15°C (a).

Length cm	Weight g	96 hr LC50 mg/l
11.9	18.3	4.52
5.6	2.0	1.19

[a]Goettl et al. 1971.

In the case of DO depletion, recent studies have shown that for combined sewer overflows, the organic matter is adsorbed by the solid surfaces of the river muds much faster than it is degraded (Harremoës, 1982; Hvited-Jacobsen, 1982 and Hvited-Jacobsen and Harremoës, 1982). This process causes a delayed oxygen depletion at the bottom of the river bed downstream of the discharge point where organic matter settles on solid surfaces. This delay effect lasts at least 12-24 hours after the discharge event. This process is illustrated in Figure 1.10.

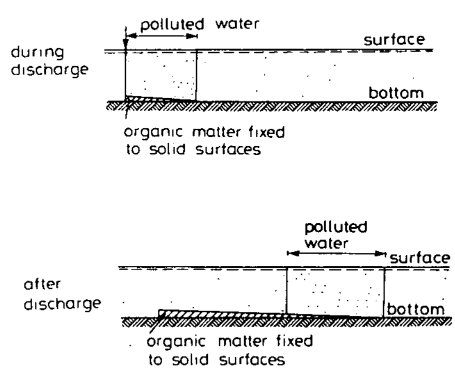


Figure 1.10. Removal of organic matter from a water volume under transport down a river. After Harremoës (1986).

The same authors found that the removal rate of organic matter by sedimentation is approximately ten times greater than the actual degradation rate. Therefore the depletion will be maximum in reaches close to the discharge point. In addition, diurnal oxygen fluctuations have also to be taken into account. The superposition of oxygen depletion caused by an event during the day with high oxygen concentrations created by photosynthetic activity is different during the night when respiration depletes oxygen resources. A three dimensional illustration of this phenomenon is shown in Figure 1.11. The graph shows that total oxygen depletion can occur during a few hours causing adverse effects to the animal population of the stream. It must be noted that the in-stream oxygen depletion is caused by a well known pollution indicator, the biological oxygen demand (BOD). Figure 1.12 illustrates the short-term impact of BOD on the in-stream DO during a storm.

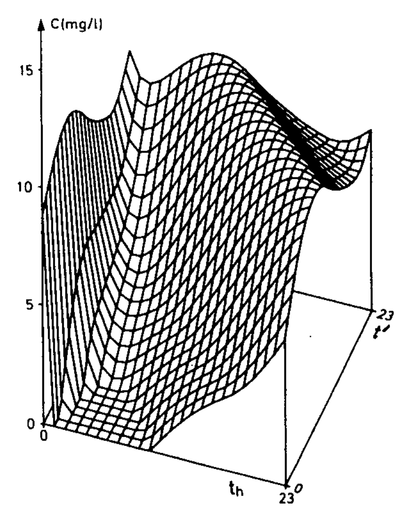


Figure 1.11. A three-dimensional illustration of the superimposition of diurnal oxygen fluctuations on the delayed oxygen sag in the river resulting from a discharge of 127 Kg COD to a river with a baseflow Qb = 50 l/s. C = oxygen concentration (mg/l); th = distance down the river as time of travel in hours; t'= time in hours after passage of the runoff volume. After Harremoës (1982).

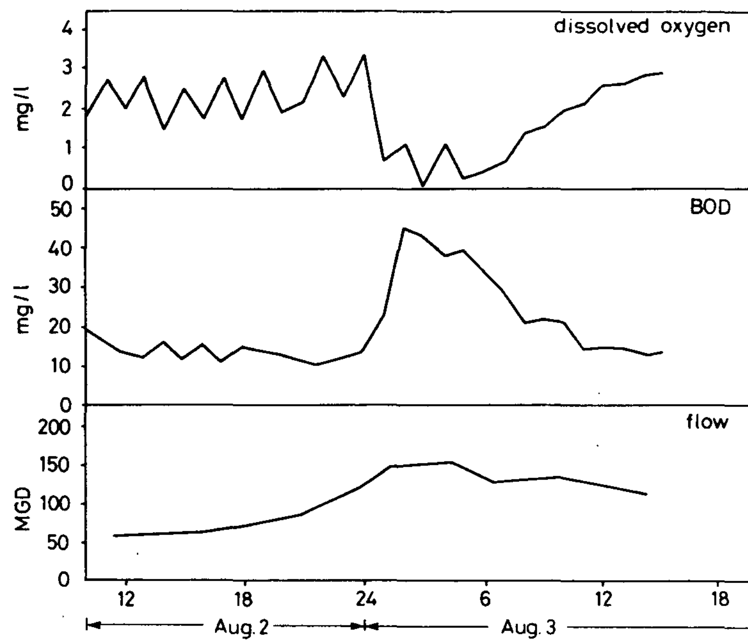


Figure 1.12. The short-term effect of a storm discharge on the river Tame, UK. After Hvited-Jacobsen (1986).

1.4.2. The Long-Term Impacts

The long term impacts of stormwater discharges are the result of an accumulative process. A gradual build-up in the concentration of the pollutant occurs in-stream or in the water body sediments. The detrimental effect appears when the concentration exceeds a threshold value. Hence long-term effects usually occur some weeks, months or even years after a series of stormwater inputs. Those effects include fish kills, eutrophication due to nutrients (phosphates, nitrates, etc.) and continued oxygen depletion due to settling-out of the BOD fraction of the suspended solids, as well as toxicity of heavy metals due to the resuspension processes. A typical example of long-term impacts of urban runoff is the dramatic changes that occurred in Lake Erie (Bastian, 1986) during the late 1960s. At that time, severe oxygen depletion and blooms of blue-green algae were observed and fish kills were common. These were the disastrous consequence of the excessive nutrient and other pollutant loads from both point and non-point sources created by a fast population growth. Beeton

(1969) indicated that ammonia-N increased fivefold and total nitrogen increased about threefold between 1930 and 1958 whereas total phosphorus concentration doubled between 1942 and 1958.

Figure 1.13 illustrates the response of long-term pollution on the fish population of Lake Erie once the threshold of tolerance has been reached.

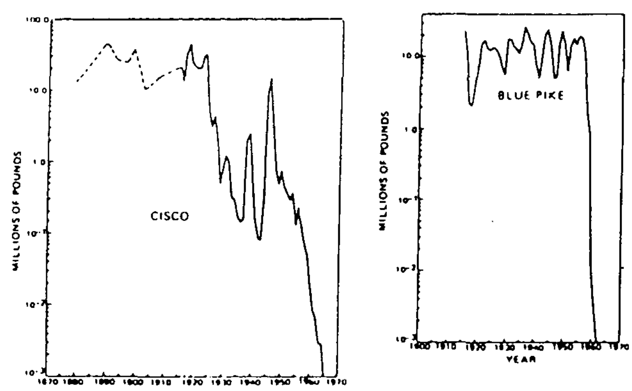


Figure 1.13. Commercial production of blue pike and cisco in Lake Erie (USA). After Beeton (1969).

In the particular case of Lake Erie it must be noticed that efforts to reduce pollution effects have resulted in dramatic and rapid improvement in water quality in the lake probably because of its very short detention time (2.6 years).

The two categories, acute and long-term effects, in terms of loads discharged, can be treated statistically in a similar way but with a different time basis. For acute effects, time scales are of the order of hours but for long terms effects, monthly or even annual data are more relevant. This approach developed by Harremoës (1986) is included in Section 1.5.2.

1.5 Review of Distribution Fitting

For the pollutant concentrations encountered in urban runoff, it is likely that exposures in terms of hours have a high probability of causing adverse environmental impacts. Hence an appropriate and convenient time scale for analysis of urban runoff loads, concentrations and effects is the event duration. The parameter analysed in this case is the average concentration of a given pollutant during the event, the event mean concentration. A considerable amount of work has been done by the US EPA using this basic average approach. Recently other researchers in Europe such as Harremoës have used the same approach but introduced the idea of using pollution load data with a different time basis (ie. yearly). In the United States and in Europe a distributional analysis was applied to EMC data in order to work out the return periods of EMCs and to test their compatibility with national standards. In all cases the lognormal distribution was considered best suited for frequency estimation of EMCs.

1.5.1 The Work Done in the United States

1.5.1.1 The Lognormality of Water Quality Data

Driscoll (1986) presented a paper in which a series of probability plots of water quality data from a variety of discharge sources was displayed. Representative examples of observed EMC and site median concentration data from highway stormwater runoff, combined sewer overflows, urban runoff point sources discharged from sewage treatment plants as well as agricultural runoff were analysed and plotted for their lognormality properties. Driscoll concluded: "such examination suggests that a lognormal distribution either actually defines the underlying population of pollutant concentrations, or is at the least a satisfactory approximation for most environmental analyses". Although all the plots displayed in the paper present a fairly good fit with the method of moments, several remarks can be made:

- the same pollution indicators were probably not available for all the differing types of pollution cited: highway runoff, urban runoff, etc.

A lack of consistency (certainly involuntary) was apparent for the pollution indicators used;

- 15 out of the 64 samples presented (23%) contained 10 or less values;

- no goodness of fit index was computed. The fit was judged by eye, hence it is difficult to quantify how good the fit actually was;

- no distributions other than the lognormal distribution were analysed or displayed.

Another paper by Strecker et. al. (1987) supported the lognormality of highway pollutant concentrations with an analysis of data from 31 sites in the United States covering a total of 993 separate storm events. The information was collected for the Federal Highway Administration. The initial assumption that EMC data for a site could be fitted by a two parameter lognormal distribution was made because, as written in this paper, "the US EPA NURP study (1983) reached a similar conclusion regarding pollutant concentrations in stormwater runoff from urban areas, based on a significantly larger data base than is available here". In the study conducted by Strecker et. al., a "probability plot correlation coefficient" (Vogel, 1986) was used as a statistical test for confidence that the distributions of EMCs for each site were lognormal. This test despite its convenience, cannot be applied to three parameter distributions. The authors concluded "almost all data sets were concluded to be adequately described by a lognormal distribution". When they examined the distribution of site median suspended solids concentrations for all highway sites, they discovered a cut-off point in the pattern suggesting that two separate lognormal distributions were present. The authors suggested that the average traffic density per day was the factor that delineated the two distributions at the threshold of 30,000 vehicles per day.

Table 1.8 summarises the successful application of the lognormal distribution over the two papers discussed previously: Driscoll (1986) and Strecker et. al. (1987).

Table 1.8. Synthesis of the successful application of the lognormal distribution as presented by Driscoll (1986) and Strecker et. al. (1987).

Origin of pollution	Type of data	Pollutants analysed
Highway runoff	EMC	TSS. Total N, TKN, Pb, Zn
Combined sewer overflow	EMC	BOD_5, TSS
Urban runoff	EMC	COD, Ptot.
Agricultural NPS runoff	EMC	N-NH_4^+, N-NO_3^-, TKN, Psol.
Treatment plant effluent	EMC	BOD_5
Highway runoff	Site median concentrations	TSS
Combined sewer overflow	Site median concentrations	BOD_5, TSS
Treatment plant effluent	Site median concentrations	Cd
Urban runoff	Site median concentrations	Ptot.
Surface and subsurface runoff of conventional tillage (agricultural runoff)	Annual average concentrations at a site	Psol., NO_3^-

1.5.1.2 <u>The Probabilistic Mass Balance Approach as a Tool for Decision Making</u>

If the lognormality of EMC data is admitted, a more integrated approach can be carried out.

In Europe, the theory of the mass balance approach for river quality modelling was first developed by Warn et. al. (1980). The computation, involving Monte Carlo simulation and the assumption that the parameters are lognormally distributed, provided appropriate results.

A probabilistic model including the mass balance equation has been proposed by the US EPA (1984) in order to determine the recurrence interval of the pollution concentration in a receiving stream and the violation frequency of water quality criteria. The same approach was proposed by Gaboury et. al. (1987) for highway runoff. They based their work on an analysis methodology initially developed by Di Toro (1984). A basic description of the method is presented here.

During a runoff event the receiving water concentration (CO) for a given pollutant depends on the upstream flow (QS), the upstream concentration (CS) and, of course, the runoff concentration (CR) and runoff discharge (QR). The mass balance equation links all those parameters:

$$CO = (DF \ . \ CR) + ([1-DF] \ . \ CS)$$

where DF (or ϕ), the dilution factor is defined as:

$$DF = \frac{QR}{QR + QS} = \frac{1}{1 + QS/QR} = \frac{1}{1 + D} \quad \text{with} \quad D = \frac{QS}{QR}$$

If we assume the variables QS, QR, CS, CR, to be lognormally distributed and independent then CO will be approximately lognormally distributed since the sums of lognormal random variables have tails which are approximately lognormal (Janos, 1970). Hence the knowledge of the parameters characterising the lognormal distributions of QS, QR, CS and CR allows the computation of the cumulative probability distribution of CO and therefore the recurrence interval (or return period) of CO will be known. This general schematic approach is displayed in Figure 1.14.

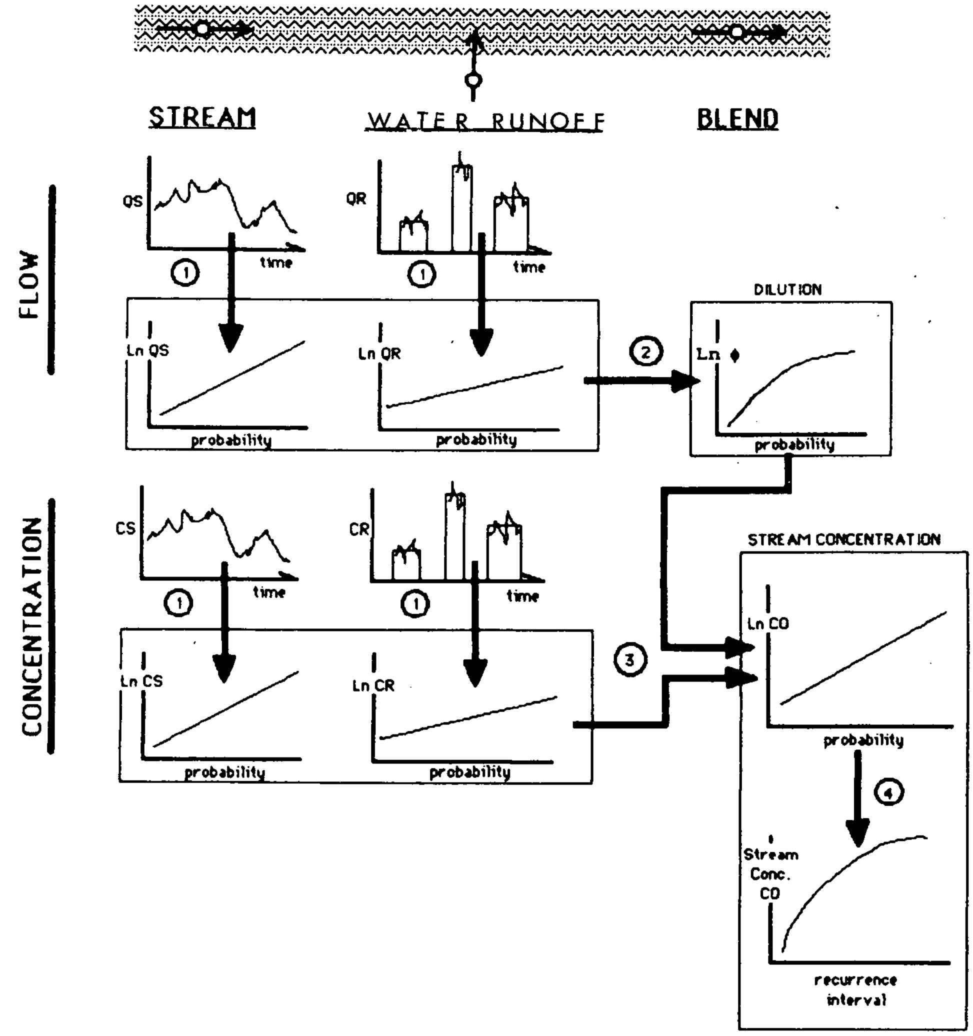


Figure 1.14. Schematic outline of probabilistic method for computing the return period of in-stream pollutant concentration due to water runoff. After Gaboury et. al. (1987).

Despite the assumptions made about the lognormality of runoff and stream flows, the dilution factor DF (or ϕ) is not truly lognormal. To calculate accurately the probability distribution of DF, a numerical procedure using quadratures is available but however a simple form of lognormal approximation is presented here. It has been emphasised that the method of moments provides a conservative computation (overestimation of the in-stream concentration for a given non-exceedance probability). However the method of moments matches quite well the exact method of quadratures between the 5% and 95% percentiles. Table 1.9 provides the basic relationship (drawn from the moments estimates) used in the computation of a lognormal distribution.

Table 1.9. Lognormal distribution relationships and terminology. After Gaboury et. al. (1987).

	ARITHMETIC	LOGARITHMIC
MEAN	M	U
STD DEVIATION	S	W
COEF OF VARIATION	CV	
MEDIAN	T	

T = exp (U)	W = SQR (LN (1 + CV^2))
M = exp (U + ½W^2)	U = LN (M / exp (½W^2))
M = T * SQR (1 + CV^2)	U = LN (M / SQR (1 + CV^2))
V = SQR (exp (W^2) -1)	
S = M * CV	

LN(x) designates the base e log of the value x,
SQR(x) designates the square root of the value x,
exp(x) designates e to the power x.

Assumming no correlation between stream and runoff flows:

$$W_D = (W_{QS}^2 + W_{QR}^2)^{1/2}$$

and the value of DF for any probability percentile α is:

$$DF\alpha = \frac{T_{QR}}{T_{QR} + T_{QS} \cdot \exp(Z\alpha \cdot W_D)}$$

where $Z\alpha$ is the standard normal variable corresponding to the probability α.

The arithmetic mean of the receiving water contaminant concentration is defined as:

$$M_{CO} = (M_{CR} \cdot M_{DF}) + (M_{CS} \cdot [1 - M_{DF}])$$

The arithmetic standard deviation is:

$$S_{CO} = S_{DF}^2 \cdot [M_{CR} - M_{CS}]^2 + S_{CR}^2 \cdot [S_{DF}^2 + M_{DF}^2] + S_{CS}^2 \cdot [S_{DF}^2 + (1-M_{DF})^2])^{1/2}$$

The corresponding log transforms must be computed to develop the desired information on probability:

log standard deviation: $W_{CO} = (\ln[1 + CV_{CO}^2])^{1/2}$

log mean: $U_{CO} = (\ln[M_{CO}/(1 + CV_{CO}^2)^{1/2}]$

Then the concentration that will not be exceeded at the probability α can be computed:

$$CO_\alpha = \exp(U_{CO} + Z\alpha \cdot W_{CO})$$

Conversely, the probability α of CO exceeding a given stream concentration CO_α can be determined with a normal probability table after computing:

$$Z\alpha = \frac{\ln[CO_\alpha]-U_{CO}}{W_{CO}}$$

In the US EPA draft report (1984), a verification of computed concentrations is proposed. Data from approximately 20 storm events acquired during the NURP program at Rapid City, was used to test the reliability of the methodology. Figure 1.15 shows the lognormality of upstream and runoff flow data whereas Figure 1.16 shows, as an example, a good lognormal fit of the downstream TSS data. The straight line represents the theoretical distribution calculated by the method of moments described in the methodology.

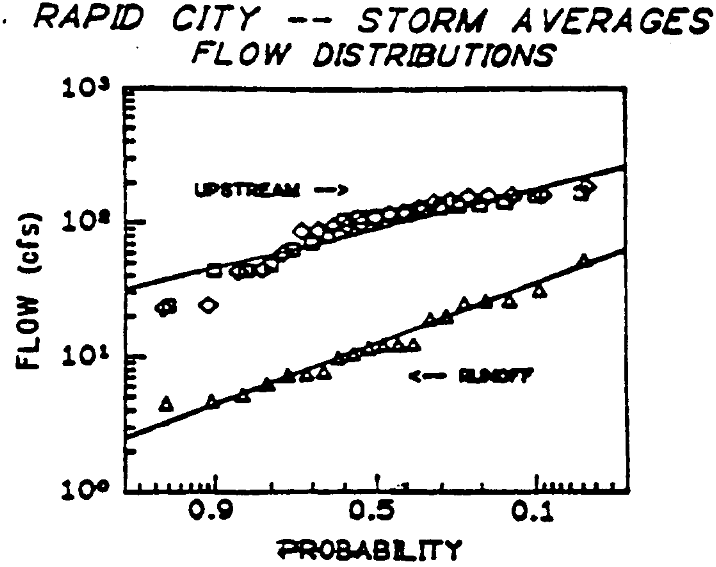


Figure 1.15. Exceedance probability distribution of stream and runoff flows. After US EPA (1984).

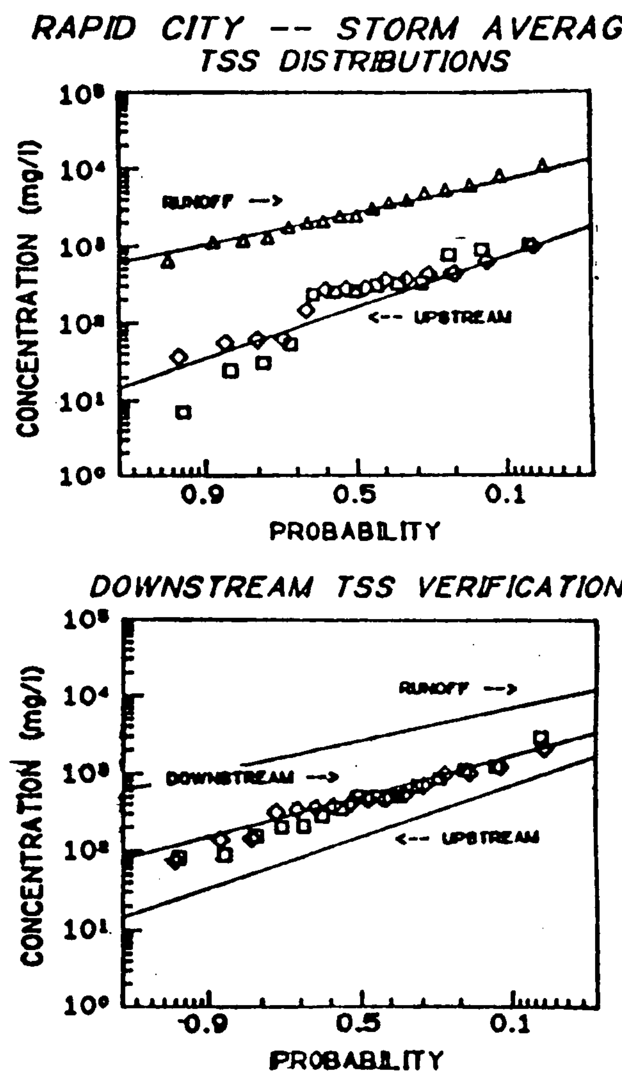


Figure 1.16. Comparison of the distribution of the concentrations in runoff, downstream and upstream locations with the theoretical probability distributions. After US EPA (1984).

The methodology described above shows good results and the mean recurrence interval (or return period) MRI can be computed from:

$$MRI = \frac{1}{(\text{exceedance probability}) \ . \ N}$$

$$MRI = \frac{1}{(1-\alpha) \ . \ N}$$

where N = number of storms per year.

Then the significance of a particular magnitude/frequency pattern of downstream concentrations caused by urban runoff can be evaluated by comparing them with a specific water quality criterion.

Figure 1.17 from the NURP final report (US EPA, 1983) illustrates such an approach. The toxicity effect levels for copper are those suggested by the NURP study for short duration exposures and are quoted for a total hardness of surface waters of 50 mg/l. In this situation the in-stream concentration of copper caused by untreated urban runoff discharges exceed the "EPA Maximum" criterion more than ten times per year on average whereas the threshold level (concerning adverse biological impacts) is exceeded, on average, five times per year (MRI = 0.2 year). It must be noted that significant mortality of more sensitive biological species occurs once every three years on average. In the case of "treated urban runoff", threshold levels are reached only once every 3 or 4 years on average. Significant mortality levels are never reached although the "EPA Maximum" criterion is exceeded once or twice a year on average. The "acceptable" frequency at which specific adverse effects can be tolerated is still a difficult and subjective problem to assess.

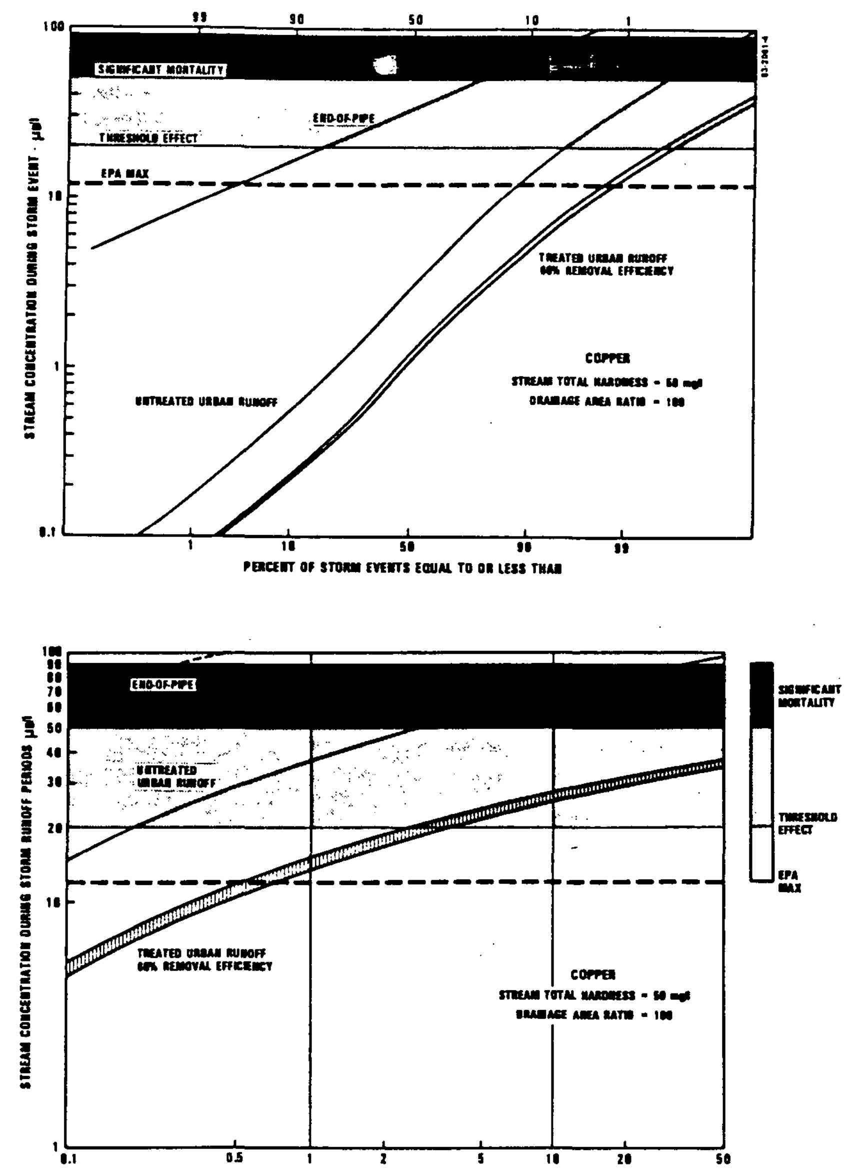


Figure 1.17. Distribution and recurrence of in-stream concentrations. After US EPA (1983).

1.5.2 European Approaches

1.5.2.1 The Lognormality of Water Quality Data

Relatively little work has been undertaken in Europe to test the lognormality of EMC data in comparison with the USA effort. Although the lognormality of EMC data is generally admitted and included in integrated probabilistic approaches, no basic or consistent work appears to have been undertaken to assess the goodness of fit of various statistical distributions.

In the UK, the conclusions presented in the status report of the European Water Pollution Control Association (EWPCA, 1987) are: "a two parameter lognormal distribution is quite adequate for urban runoff data and can be completely specified by a central tendency and a dispersion parameter. However, because of its several assumptions and its inability to simulate control alternatives explicitly, the log frequency distribution approach is probably best suited for general management/planning survey work". Figure 1.18 displays the graph presented in the EWPCA report to illustrate the lognormality hypothesis.

In another paper from Pratt et. al. (1987), the hypothesis of lognormality distribution of suspended solids EMCs in flows from highway gullies was tested graphically, and the authors concluded: "the hypothesis was confirmed and close fit achieved to the assumed mean and standard deviation". Figure 1.19 shows the graph presented by the above authors.

In Denmark some work presented by Harremoës (1986) gives evidence of a good visual fit of the two parameter lognormal distribution to EMC data sets. A bulk sample of COD data sets drawn from two combined systems was successfully fitted by a lognormal distribution. The same result was achieved for a bulk sample of COD data drawn from three separate systems. Figure 1.20 displays those plots and the small table insert presents some basic statistics of the observed distributions.

Although graphical tests of goodness of fit are essential, all the examples cited in this section do not include statistical tests that would allow the reader to quantify the so called "good fit".

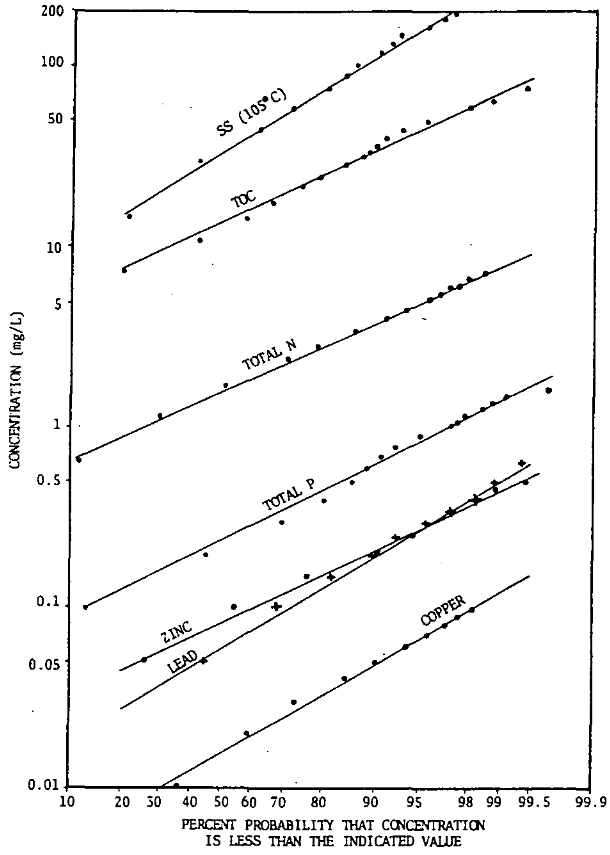


Figure 1.18. Lognormal probability plots of EMC data from the UK Oxhey separately sewered catchment in North London. After EWPCA Status Report (1987).

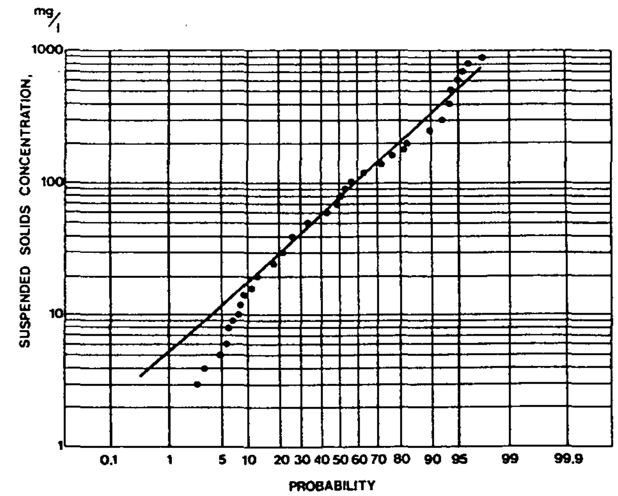
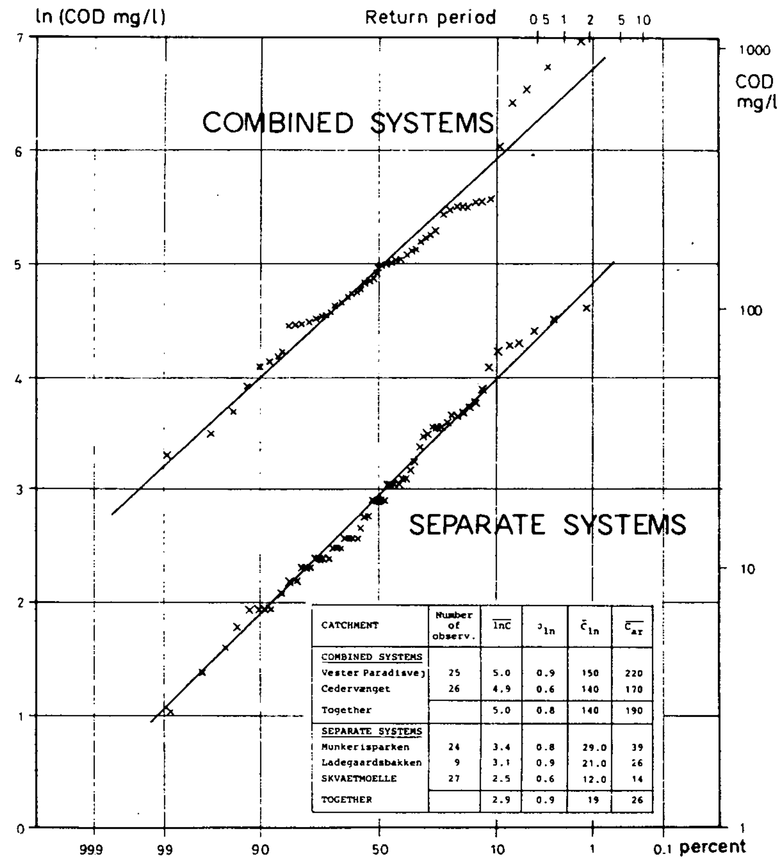


Figure 1.19. Lognormal probability distribution plot of suspended solids EMCs in flows from highway gullies (Nottingham). After Pratt et. al. (1987).



CATCHMENT	Number of observ.	$\overline{\ln C}$	σ_{ln}	$\bar{C}_{ln}$	$\overline{C_{ar}}$
COMBINED SYSTEMS					
Vester Paradisvej	25	5.0	0.9	150	220
Cedervænget	26	4.9	0.6	140	170
Together		5.0	0.8	140	190
SEPARATE SYSTEMS					
Munkerisparken	24	3.4	0.8	29.0	39
Ladegaardsbakken	9	3.1	0.9	21.0	26
SKVAETMOELLE	27	2.5	0.6	12.0	14
TOGETHER		2.9	0.9	19	26

Figure 1.20. Lognormal distribution of COD EMC in runoff from separate and from combined sewer systems in Denmark. The table gives the distribution characteristics: lnC is the mean of the logarithm of the concentration in mg/l, σ_{ln} is the standard deviation of lnC, $\bar{C}_{ln} = e^{lnc}$, $\bar{C}_{ar}$ is the arithmetic mean. After Harremoës (1986a).

1.5.2.2 A Probabilistic Approach to Assess Stormwater Runoff Impacts: the Danish Example

The Approach for Short-term Effects

As previously described, short-term effects can be assessed in terms of concentration or load of a given pollutant for individual events. Harremoës (1981, 1986a, 1986b) has been the main proponent of this probabilistic approach.

The Danish Water Quality Standards

Harremoës et. al.(1982) proposed an in-stream oxygen concentration standard based on single event statistics. This standard combines concentration, event frequency and event duration and type of river. This standard, as a wet weather standard, is different from dry weather standards where frequently only a single number is used. Appendix 1.1 shows extracts of EEC water quality standards (percentile standards) for surface water intended for the abstraction of drinking water and freshwater supporting fish life. Figure 1.21 presents the Danish standards recommended by the Danish Water Pollution Control Committee for two durations of DO depletion (1 and 12 hours) and for three types of water quality (habitats for spawning fish, salmon and carp). The standard expresses the required oxygen concentration as a function of return period. The criterion selected is that half the fish population may be killed at the concentration and duration, indicated for the rarest events; 8, 12 and 16 year return period. These standards have been derived from literature studies on the effects of low oxygen concentrations, referenced in Hvited-Jacobsen (1984).

In the case of the DO standard, the directives from the EEC for salmonid waters and the standards proposed by the Danish Water Pollution Control Committee for trout rivers are not easily comparable but the second one could be complementary to the first one when, as written in Appendix 1.1, "major daily variations are suspected" (in the case of urban runoff for example).

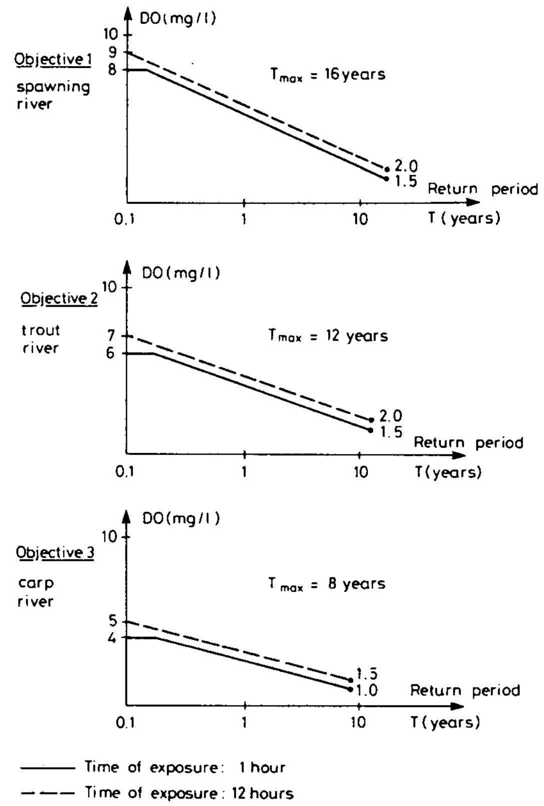


Figure 1.21. Danish standards recommended by the Danish Water Pollution Control Committee for oxygen concentrations in rivers affected by combined sewer overflows. After Harremoës (1986b).

DO concentrations in the river can be calculated using historical rain series as input to simulation models. Figure 1.22 shows the comparison between Danish standards and calculated instream DO concentrations due to combined sewer overflows.

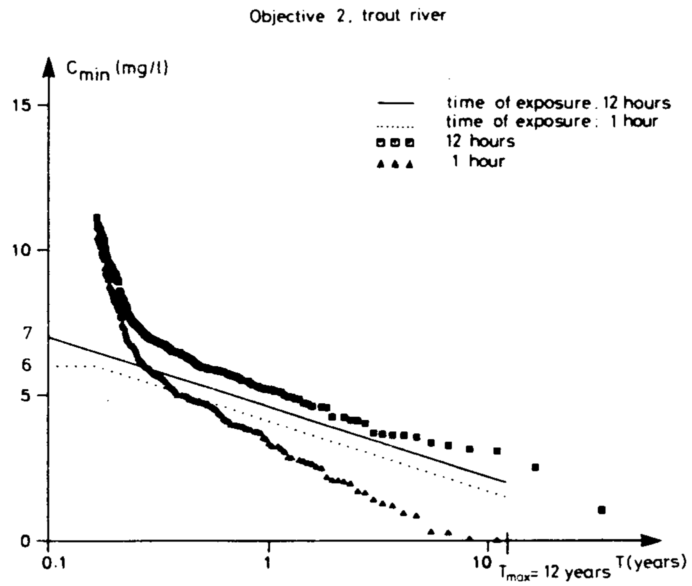


Figure 1.22. Plot of required and predicted oxygen concentrations in Danish river affected by combined sewer overflows. After Harremoës (1986a).

The Mass Balance Modelling

If the parameter that matters in terms of impact is considered to be the load of COD or BOD discharged during a storm event then a mass balance approach can be applied (Harremoës, 1986b).

The event mass discharge (M) is derived by multiplication of the event mean concentration (C) by the volume of discharge (V):

$$M = C.V$$

If ln(C) and ln(V) are independent and normally distributed with known mean m and standard deviation σ then ln(M) is approximately lognormal:

$$\ln(M) = \ln(C) + \ln(V)$$

and $m_{ln(M)} = m_{ln(C)} + m_{ln(V)}$

$$\sigma^2_{ln(M)} = \sigma^2_{ln(C)} + \sigma^2_{ln(V)}$$

The hypotheses of lognormality and independence are now examined.

The lognormality of EMC data has been demonstrated for COD as shown in Figure 1.20.

Concerning rainfalls, the natural logarithm of rain volume data at Odense in Denmark has been plotted on Figure 1.23. The distribution is skewed because of the cut-off point of 3mm rainfall which is used for screening the data. However data higher than the median value do appear to be lognormally distributed. Rain volumes are then changed into actual runoff volumes by a simple multiplication of the runoff coefficient.

After an analysis of independence between the parameters Harremoës concluded: "the concentration can be considered statistically independent of rain and discharge volume". All the conditions being satisfied the return period of event load of COD can be determined as shown on Figure 1.24 for both separate and combined systems. The steepest of the lines accounts for the variability of the concentration while the other curve is based on multiplication of each discharge volume of the rain series with the log-mean concentration without regard to the variability of the concentration. The distance between the two lines is determined by a correction factor depending on the return period.

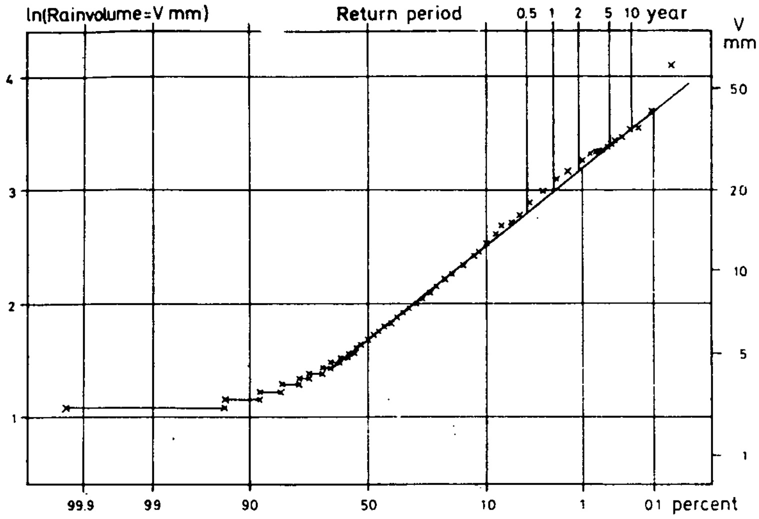


Figure 1.23. The lognormal distribution of rain volume from a historical rain series covering 33 years, containing 1571 individual rain events larger than 3mm from the town Odense in Denmark. After Harremoës (1986a).

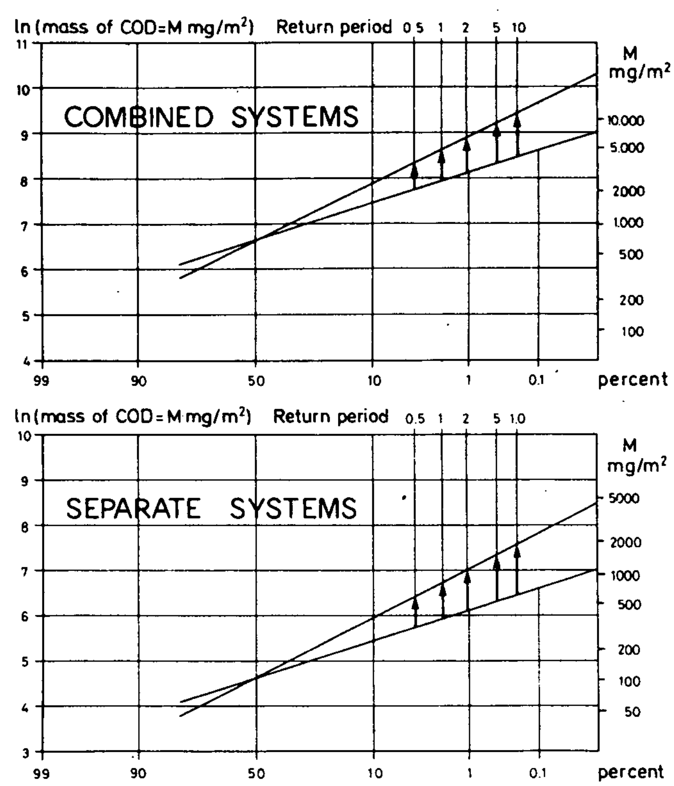


Figure 1.24. The lognormal distributions of discharge of COD per rain event and per specific catchment area for separate sewer systems and for combined sewer systems in Denmark. After Harremoës (1986a).

The Approach in the Case of Long-term Effects

In the case of long-term effects of stormwater runoff, the evaluation of pollution discharged has to be based on a yearly basis to model, for example, eutrophication effects. There can be a very significant statistical variability from year to year in the runoff loading as shown on Figure 1.25 and Figure 1.26. So far no standards on a yearly basis have been proposed.

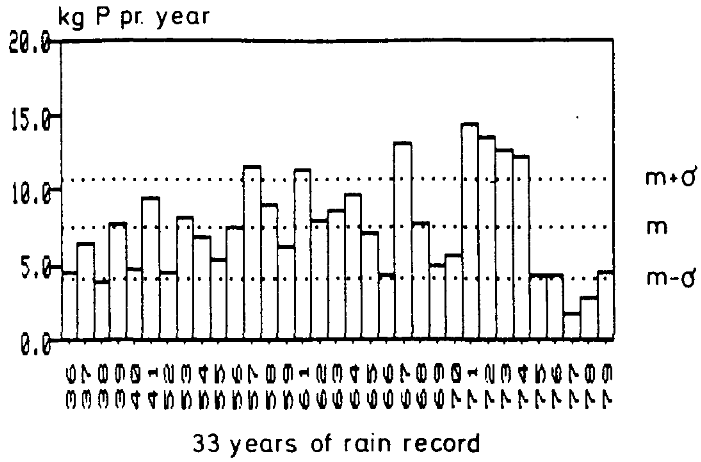


Figure 1.25. Distribution of yearly discharge of phosphorus to a Danish lake from a combined sewer overflow structure calculated with a 33 year rain record as input to a runoff simulation model from the MOUSE package. After Harremoës (1986a).

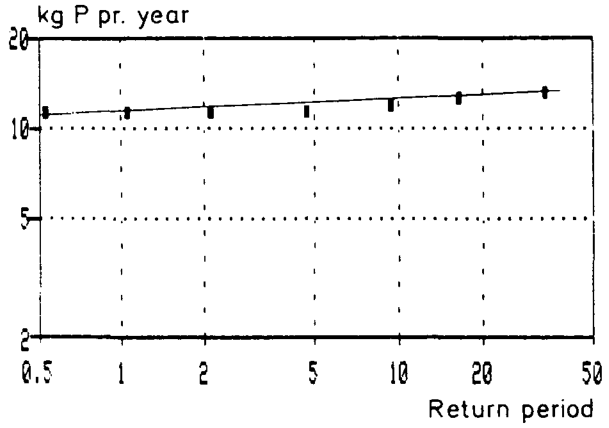


Figure 1.26. Plot of statistical distribution of yearly phosphorus load as a function of return period. Data corresponding to Figure 1.25. After Harremoës (1986a).

1.6 Conclusion

In this chapter, the presentation of up to date statistical models reveals that these are normally constructed on the assumption of a well known underlying statistical distribution. The convenience and the properties of the lognormal distribution make it particularly suited to be integrated in a mass balance model. However no consistent studies using statistical tests and testing several distributions seem to emerge. It is of importance to tackle the problem of "best-suited" distribution in a consistent way in order to derive reliable EMC return periods for a given catchment and a given pollution indicator.

CHAPTER 2: THE DATA USED

2.1 The French Urban Runoff National Programme

2.1.1 Context and Background

In 1978, the Service Technique de l'Urbanisme from the Ministère de l'Environnement et du Cadre de Vie, aware of the potential pollution problems caused by urban runoff in France, established a working group to review three objectives:

- characterisation of catchments and the "pathology" of sewage networks;
- to define technical aspects of measurement and interpretation of data;
- to identify appropriate approaches to resolve the runoff pollution problem.

Those objectives were defined after unconclusive results were drawn from existing data. Hémain (1981), using pre-1980 data from French and North American catchments, concluded that it was not possible to highlight strong links between pollutants (BOD, COD, TSS) and hydrological characteristics and land use types. The variability and incoherence of the derived results were probably due to the measurement procedure rather than the misunderstanding of the actual runoff processes involved. Hémain stated that initial data was collected at the outlet of catchments and therefore included the combination of several undesirable parameters such as the variability of drainage system type, the variability of measurement devices, the variability of hydraulic design, leaks from the network, seepage of more or less polluted water, atmospheric pollution, etc. A global and consistent approach as well as a thorough investigation of selected catchment characteristics were to be undertaken as part of the National Programme.

The existing data being inadequate, the working group decided that it was necessary to start a national data collection programme in France. Two targets were therefore defined:

- an estimation of the annual average loadings of various runoff pollutants from varying urban land uses in order to define, in the long term, their likely impacts upon the receiving environment;

- an estimation of severe or acute pollution hazards that could impair receiving steam quality over very short time periods.

The working group then commissioned a data collection methodology to be undertaken within suitable urban catchments.

Four separately sewered catchments were eventually chosen as experimental units: Les Ulis and Maurepas are located in the Paris area whereas Aix-Nord and Aix-Zup which are located in the Aix-en-Provence area (South of France). The data collection started in September 1980 and ended in December 1982. The measuring equipment set up in each catchment comprised:

- an autographic raingauge (Précis Mécanique PL 1000);
- a flowmeter including an air pressure sensor (ISCO 1870);
- two automatic samplers, one collecting a bulk sample in a single container (ISCO 1580) and another one collecting fractionated samples (ISCO 1680).

Technical maintenance was ensured at least three times a week.

2.1.2 Outcome of the Data Collection Programme

According to a previous report (Hémain, report LHM 25/1983, 1983), the outcome of the programme was regarded as being very satisfactory since:

- the measurement equipment was found to be very reliable with breakdown rates lower than 10%;
- the volume of data collected was very large as Section 2.3 of this report shows;
- numerous data derived from each storm event permitted a check on the samples to ensure they give mean samples and thus are representative of the runoff at the measuring point. A comparative study carried out on a given parameter during a given event has shown that an accuracy of ±30% can be associated with the pollutant concentration data;
- a careful evaluation of the data was carried out by the creation of computerised files containing information such as flow rates, mass loads, pollutant concentrations, rainfall volumes/intensities, etc.

However, two anomalies were detected:

- the observed runoff volume on the Aix-Nord catchment is believed to be too small. A runoff coefficient of 35% was expected instead of the 12% figure that was actually derived. The origin of this anomaly could not be determined despite thorough complementary research;

- dry weather flows carried by the Les Ulis drainage system were found to be quite polluted. The presence of foul water in the system was suspected.

2.2 Characteristics of the Catchments

The main characteristics of the four catchments studied in the French National Programme are presented in Table 2.1. More detailed information is gathered in Appendix 2.1.

Table 2.1. Characteristics of the catchments of the French National Runoff Programme. After Hémain (report LHM 25/1983, 1983).

catchment / characteristics	MAUREPAS	LES ULIS	AIX ZUP	AIX NORD
Total area (ha)	26.7	43.1	25.6	92.0
Average slope (%)	0.5	0.55	2.9	6.5
Impervious area (%)	60	42	78	35
Nature of the ground	silt-clay with millstone (little perviousness)	silt-clay with millstone (little perviousness)	marl under scree (impervious)	scree-calcareous marl (impervious)
Individual housing, i.e detached/ semi-detached (% of total area)	70	0	4	7
Collective housing i.e multistorey/blocked (% of total area)	17	100	27	13
Kind of roofing on collective housing	flat	flat	flat	40% flat 60% sloped
Population density (inh./ha)	95	340	210	35
Sewer type	separate	separate	separate	separate
Pipe size at measuring point	T 130,80	Φ 1800 mm	Φ 1200 mm	T 180-108
Slope at measuring point (%)	0.5	0.1	1.7	2.0
Measurement period	09/80-12/80 12/81-12/82	12/81-12/82	10/80-02/82	10/80-02/82

2.3 The Data Collected under the French Programme

2.3.1 Operational Performance of the Recording Equipment

A subsequent report (report LHM 09/1986) has presented the data which have been collected under the French National Programme and their corresponding computerised files. This section briefly summarises the relevant points drawn from this report.

Table 2.2 displays the performance of the various measuring apparatus and it is important to note:

- the number of runoff events recorded at Aix-Nord is similar to that at of Aix-Zup because of the geographic proximity of the two catchments. However the number of events is lower at Les Ulis than at Maurepas. This difference can be explained by the fact that more rainfall is needed over the Les Ulis catchment to initiate the runoff process;
- the efficiency of the raingauges varies from 73% to 85% which is considered to be satisfactory;
- the efficiency of the flowmeters is high varying from 81% to 92%;
- the efficiency of the samplers can also be considered as satisfactory since:
  (1) basic chemical analyses (COD, BOD_5, TSS) have been completed for 68% to 80% of the sampled events;
  (2) at least 18 pollutants out of the 21 pollutants presented have been analysed, for 36% to 59% of the total number of events. The efficiency at Aix-Nord is the lowest in this respect. This is due, firstly, to more flowmeter breakdowns than normal and, secondly, to insufficient collected volumes as the triggering switch was placed too high in comparison with the expected water level. If only 14 pollutants are considered, the sampling efficiency increases to 47% for this catchment;
  (3) Proper pollutogrammes have been worked out for 64% to 79% of the events for which runoff volume was abundant enough to fill the bottles.

Table 2.2. Efficiency of measurements under the French National Programme. After the Laboratoire d'Hydrologie Mathématique (1986).

catchment	MAUREPAS	LES ULIS	AIX-ZUP	AIX-NORD
Total number of events (TNE)	174	97	75	73
RAINFALL				
Number of measured events (NME)	151	88	73	71
Correct recordings (CCR)	156	85	69	59
Efficiency: CRR/TNE (%)	75	85	85	73
DISCHARGE				
Number of measured events	172	90	73	66
Correct readings (CRD)	156	85	69	59
Efficiency: CRD/TNE (%)	90	88	92	81
CHEMICAL ANALYSES				
Number of sampled events	153	88	56	51
Number of uniform sampled events (NUSE)	125	78	52	50
Efficiency 1: NUSE/TNE (%)	74[2]	80	69	68
Number of uniform sampled events with at least 18 pollutants analysed (NUS18)	79	47	41	26
Efficiency 2: NUS18/TNE (%)	53[2]	59[2]	55	36
POLLUTOGRAMMES				
Number of possible pollutogrammes (NPP)	29[2]	22[2]	23	13
Number of actual pollutogrammes (NAP)	23	14	16	9
Efficiency: NAP/NPP (%)	79	70	69	

[2] Corrected value taking into account the number of events not analysed for financial reasons.

2.3.2 Description of the Computerised Files

The raw data as first collected was organised into raw files which have been reviewed and corrected when necessary. After this essential step, four kinds of file were set up for each catchment:

- the corrected raw files;
- the "event" files;
- the "pollutogramme" files;
- the "event mean concentration" files.

The following section describes the content of those files.

2.3.2.1 The Corrected Raw Files

For each of the four catchments, four raw files contain the entire information collected. The content of the four files is as follows:

The raw files for "rain" contain:

- technical characteristics and geographical location of the raingauges. Calibration corrections to be made are also indicated;
- date of the raingauge starting up;
- sequence for each measurement (or rain event): quality code of the rainfall measurement, amount of rainfall, date of measurement.

The raw files for "discharge" contain:

- technical characteristics of the apparatus and characteristics of the measuring section. The flow calibration figures are also provided in the file;
- date of the raingauge starting up;
- sequence for each measurement (or discharge event): quality code of the flow measurement, flow measurement, date of measurement.

The raw files for "event mean concentration" contain:

- technical characteristics of the sampling instruments;
- date of the sampler starting up;
- sequence for each sampled event: dates of starting and ending of the

sampled event, quality code of the mean sample, volume of the mean sample, number of analysed pollutants, code of the analysed pollutant No 1, concentration of the corresponding pollutant No 1, code of the analysed pollutant No 2, concentration of the analysed pollutant No 2, etc.

The number of analysed pollutants depends on the amount of pumped water. The parameters COD, BOD_5 and TSS are the parameters that were consistently and systematically analysed. The complete list of the pollutants that should be analysed if a sufficient amount of water was available is:

- COD, BOD_5, TSS, organic fraction of TSS, mineral fraction of TSS, COD after a two hour decantation, BOD_5 after a two hour decantation;
- lead, mercury, nickel, chromium, copper;
- kjeldahl nitrogen, ammoniacal nitrogen, nitrates, orthophosphates, total phosphorus;
- non-floating hydrocarbons, phenols.

The raw files for "split sample" contain:

- technical characteristics of the sampling instruments;
- date of the sampler starting up;
- sequence for each sampled event: dates of starting and ending of the sampled event, quality code of the split samples, number of bottles analysed, number of analysed pollutants, identification number of the bottle, dates of starting and ending of the bottle filling period, code of the analysed pollutant No 1, concentration of the pollutant No 1, code of the analysed pollutant No 2, concentration of the pollutant No 2, etc.

The parameters COD, BOD_5 and TSS were always analysed whenever possible.

2.3.2.2 <u>The Files for "Events"</u>

These files have been drawn from the corrected raw files with one "event" file created for each flow event. In the case of the Maurepas catchment, for example, 174 "event" files have been created.

Each file contains several parts:

- the first line provides general information about the flow event, the rain event and the sampling event. No flow rates, rainfall or concentration values are given here;
- the second line presents the starting date of the flow event and the dry weather flow;
- the third line provides several pieces of information about rainfall such as the starting date of the rain, the rainfall amounts during the event and during the previous one, the rainfall amounts during the last 7, 14 and 28 previous days, the number of sub-events during the rain time;
- the values contained in this first block are flow and time data that can be plotted as the hydrograph;
- the second block contains data to plot the hyetograph;
- in the third block, the event mean concentrations are given for five pollutants;
- the fourth block contains data to plot several pollutogrammes (COD, BOD_5, and TSS constituting the important parameters).

2.3.2.3 The Files for "Pollutogrammes"

These files have also been drawn from the corrected raw files whenever it was possible to do so. Each file contains several parts. The first five parts are similar to those presented in the files for "events". The sixth part provides several sequences. Each sequence gives: the number of the event, the recording number, the bottle number, the dates of starting and ending of the filling period for each bottle, the runoff volume of the event, the code of the analysed pollutant No 1, the concentration of the analysed pollutant No 1, the code of the analysed pollutant No 2, the concentration of the analysed pollutant No 2, etc.

The number of pollutogrammes (see Table 2.2) is smaller than the number of events because it was not always possible to construct a satisfactory pollutogramme. Figure 1.8 displays the pollutogramme of the third event at Maurepas.

2.3.2.4 The Files for "Event Mean Concentrations"

Three types of files for "event mean concentrations" have been created for each of the four catchments. The structure of the three types of file is presented here.

The type 1 file contains:

- event number;
- event date;
- quality code for flow data;
- total runoff volume during the event;
- runoff duration;
- maximum flow recorded;
- dry weather flow;
- quality code for rainfall data;
- amount of rainfall measured by the raingauge;
- amount of rainfall measured by the total rainfall recorder (bucket);
- duration of rainfall;
- maximum intensity over the time of concentration;
- maximum 5 min. duration intensity;
- dry weather duration before the event;
- amount of rainfall that has fallen during the last storm event;
- amount of rainfall that has fallen during the dry weather duration before the event considered (without causing any runoff);
- amount of rainfall that has fallen during the last 7, 14, and 28 previous days;
- event mean concentration of various pollutants: COD, BOD_5, TSS, percentage of organic matter contained in TSS, COD after a two hour decantation, BOD_5 after a two hour decantation, lead, mercury, zinc, cadmium, nickel, chromium, copper, kjeldahl nitrogen, ammoniacal nitrogen, nitrates, orthophosphates, total phosphorus, non-floating hydrocarbons, phenols;
- a code indicates whether the analyses have been carried out using the global mean sample or choosing the global mean sample reconstituted with the split bottles. A combination of the two possibilities can also be used.

The type 2 file contains the same information given by the type 1 file but the event mean concentrations for the three main pollutants have been deduced from the pollutogrammes when possible. These concentrations are considered to be more accurate when they are drawn from the pollutogrammes.

The type 3 file contains less general information than the type 1 file but the estimated COD, BOD_5 and TSS loads carried during the event are provided.

2.4 The Data Used in this Report

All the files detailed in the previous sections have been computerised as a data base on a magnetic tape. The files are recorded in EBCDIC format with lines containing up to 80 characters. ASCII files were drawn from the tape in order to be used on IBM PC compatible computers. All the files previously described, except the "events" files, have been purchased by the Middlesex Polytechnic Centre for Urban Pollution Research. They are now available, as ASCII files, on floppy discs.

The event mean concentrations used in this research come from two sources:

- the COD, BOD_5 and TSS data for the four catchments have been drawn from Hémain (1983). These data are presented in Appendix 2.2. These data have been originally drawn from the type 2 files for "event mean concentrations". The data corresponding to the variable "NUM" > 1000 have not been used in this report because they are the concentrations of multiple mean samples (the mean sample analysed corresponds at least to two successive flow events);
- the zinc, nitrates and ammonia event mean concentrations have been drawn from the type 2 "event mean concentrations" files and are included in Appendix 2.2. A type 2 file is presented in Appendix 2.3. As previously stated, the concentrations worked out for multiple mean samples have not been used in this report.

Table 2.3 displays the number of usable EMCs for all the analysed pollution parameters.

Table 2.3. Number of available EMCs for each catchment and each pollution parameter. After le Ministère de l'Urbanisme, du Logement et des Transports (1985).

Indicator	Detection Threshold	Catchment							
		MAUREPAS (174 events)		LES ULIS (97 events)		AIX-ZUP (75 events)		AIX-NORD (73 events)	
		(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)
COD	4 mg/l O_2								
TSS	2 mg/l								
BOD_5	2 mg/l O_2								
COD*	4 mg/l O_2								
BOD_5*	2 mg/l O_2								
Pb	0.0015 mg/l	107	87	63	57	19	19	18	16
Hg	0.0001 mg/l	61	59^{29}	52	49^{33}	19	19^{2}	18	16^{2}
Zn	0.01 mg/l	107	87	52	56	19	19	18	16
Cd	0.0002 mg/l	107	87	52	49	19	19	18	16
Ni	0.001 mg/l	88	76^{3}	52	49^{4}	19	19	18	16
Cr	0.0005 mg/l	88	76	52	49^{2}	19	19	17	15^{2}
Cu	0.001 mg/l	107	87	51	48	0	0	0	0
N kjeldahl	0.05 mg/l N	98	79	47	44	47	47	33	31
NH_4^+	0.02 mg/l N	98	79	47	44	48	48	37	35
NO_3^-	0.1 mg/l NO_3	98	79	47	44	48	48	36	34
o-PO_4^{3-}	0.1 mg/l PO_4	79	68	47	44	47	47^{1}	34	32
total P	0.1 mf/l P	79	68	47	44	41	41^{1}	25	24
N/F HCs	0.04 mg/l	86	70	46	43	20	20^{5}	7	6^{2}
phenols	0.025 mg/l	28	26^{24}	12	11^{11}	34	34^{6}	19	18^{1}

(A) Number of analyses performed on a given pollution parameter.

(B) Number of correct data usable for statistical purposes.

* After a 2 hour settling period.

Superscripted values represent the number of analysed values less than the detection threshold.

N.B. when the heavy metals samples arrived in the laboratory, they were acidified (HNO_3, 1 ml/l) and then kept in glassware. Afterwards the samples were filtered and the filtrate analysed by atomic absorption spectrophotometry.

2.5 Review of Work Previously Undertaken on the Data

Some analytical work has already been undertaken on the data derived from the French National Programme. Hémain and Servat from the "Laboratoire d'Hydrologie Mathémathique" (Université des Sciences et Techniques du Languedoc, Montpellier, France) are the main researchers who have published some work on the data collected during this programme. Hémain (1983, 1984) presented a thorough data investigation which has been issued in four reports. The main findings have been collated into a single report (le Ministère de l'Urbanisme, du Logement et des Transports, 1985). Some of these findings are detailed here.

2.5.1 The Main Pollution Parameters (COD, BOD_5, TSS)

2.5.1.1 General Statistical Analysis

COD, TSS and BOD_5 parameters appear to be rather well correlated. They are better correlated for the Paris catchments (R=0.7 to 0.9) than at Aix-en-Provence (R=0.4 to 0.8) for both EMCs and events loads. The best correlations have been found between COD EMCs and BOD_5 EMCs (R=0.83 to 0.97).

The variable which best explains the variation of the main pollutants EMCs is the length of dry weather duration occurring before the event although the correlation is still relatively poor ($R \leq 0.7$). For the Paris catchments, the use of the maximum 5 min duration rainfall intensity or the amount of rainfall as a second variable in a multiple correlation analysis, increases significantly the correlation with, respectively, TSS EMC and COD EMC. The work carried out on TSS EMCs from the French National Programme by Desbordes and Servat (1984), involving classical regression analysis, principal components analysis and the Kalman filtering procedure, leads to the same conclusions:

- "antecedent climatic conditions during a not well defined period preceding a given rainfall event have great influences on TSS values";
- "the whole solids transform process cannot be precisely modelled by a linear model between TSS and hydrological or classical parameters".

The two authors cited above pointed out that 50% of the total variance of TSS is explained by two variables: the maximum 5 min duration rainfall intensity and the dry weather duration.

For the event loads, the best variable which explains the variation in concentrations is the maximum flow rate or the maximum rainfall intensity divided by the concentration time. The dry weather duration is not very strongly correlated with the main pollution parameters loads but can be the second or third main variable in a multiple regression equation. Ellis et. al. (1985) found that up to 99% of the variance of highway runoff TSS loadings could be explained by three parameters which are, in order of importance: the total surface discharge, the antecedent dry period length and the total rainfall volume.

2.5.1.2 Statistical Analysis of the Highest EMCs

Significant correlations have been noted, mainly for the Paris catchments, between the concentration of organic matter and the dry weather duration before the event. For example, the correlation coefficient between COD and dry weather duration was R=0.88 (N=15) at Maurepas and R=0.85 (N=13) at Les Ulis.

At Aix-en-Provence, the only noticeable correlation appears between the TSS EMC and the mean maximum rainfall intensity during the time of concentration.

Nevertheless, given the few strong correlations that have been noted, it seems that the main explicative variable is missing. It could be the mass of pollutants built up over the catchment at the beginning of the rain. It could also be referred to solids deposited in the sewer pipe following an event and which are flushed out on the rising limb of the following storm event.

2.5.1.3 Statistical Analysis of the Highest Loads

No strong statistical links have been found for the highest mass loads, except between the TSS and the peak flow rate for the Aix-en-Provence catchments. The correlation between the TSS event loads and the peak flow rate is R=0.73 (N=19) for the Les Ulis catchment whereas R=0.97 (N=16) for the Aix-Zup catchment and R=0.96 (N=13) for the Aix-Nord catchment. The dry weather duration does not appear to be a principal variable in explaining the highest loads.

A load analysis has shown that the loads removed during a single event can reach:

- 3 to 7 tonnes of TSS;
- 1 to 3 tonnes of COD;
- 0.1 to 0.2 tonnes of BOD_5.

The corresponding rainfalls are characterised by their high depths and intensities. However the associated discharges correspond to events presenting a return period of up to 2 years. We can therefore conclude that the highest estimated mass loads over the period are not due to exceptional events. This conclusion confirms the generally held view that it is the more frequently occurring events that are of significance for receiving waters.

2.5.1.4 Estimation of the Annual Polluting Loads

The procedures and the figures presented here are drawn from Hémain (report No 2, 1983).

Table 2.4 shows the annual estimated loads of pollutants discharged from the respective catchments. The loads are representative of the real loads removed during the year of measurement. However the figures are unlikely to characterise the loads for a typical mean year because the year 1982 was exceptionally wet with high rainfall intensities being recorded in the Paris area. The year 1981 (when measurements were made at the Aix-en-Provence catchments) is, on the other hand, a rather dry year.

Table 2.4. Annual estimated loads removed from the four experimental French catchments. From Hémain (report No 2, 1983).

Catchment	Annual Load (kg)	COD	SS	BOD5
		Pollutants		
MAUREPAS	Total	10 000	25 000	1 500
	Per hectare	380	940	55
	Per impervious ha.	630	1 550	95
LES ULIS	Total	20 000	48 000	3 800
	Per hectare	460	1 100	85
	Per impervious ha.	1 100	2 650	210
AIX-ZUP	Total	11 000	16 000	2 000
	Per hectare	430	630	75
	Per impervious ha.	550	800	100
AIX-NORD	Total	15 000	27 000	2 500
	Per hectare	160	300	30
	Per impervious ha.	470	840	80

The annual loads seem to be rather higher on the Les Ulis catchment. This fact is almost certainly due to the presence of possible foul water in the separate drainage system. The relatively low loads recorded at Aix-Nord is most probably linked with the particularly small runoff coefficient noted on this catchment.

It was noticed that the first portion of the first runoff volume of the hydrograph carries a heavy polluting load when the flow rate is high. Hence the major events recorded carry most of the pollution load. The five most polluting events collectively carry, 29% of the total annual load of COD at Maurepas and 46% at Aix-Zup. The figures for TSS are 49% and 51% respectively. The results confirm the high potential polluting role of urban runoff:

- in terms of concentration, the average annual figures vary from one catchment to another between 100 to 300 mg/l for COD, 200 to 500 mg/l for TSS and 15 to 45 mg/l for BOD_5. The figures exceed the authorised limits for sewage treatment plant outlets which are, according to the UK Royal Commission standards, 20 mg/l for BOD_5 and 30 mg/l for TSS.

- in terms of total loads, the quantities of TSS and COD represent 30% to 100% of the outlet loads of an average sewage treatment plant. For BOD_5 the percentage vary between 10% and 20%.

2.5.1.5 The Modelling Approach

In order to reproduce the TSS, COD and BOD_5 loads for the three out of the four catchments (Aix-Zup, Les Ulis and Maurepas), a modelling approach, involving the production-accumulation and surface transport mechanisms, was carried out by Servat (1984, 1986).

A two-step approach taking into account accumulation and transport processes was first proposed and good results were obtained with TSS. A linear accumulation model was chosen. It involved a constant daily production rate and the assumption that, over a long enough time period, the total mass produced will be removed. A three-variable model was set up to describe rainfall-runoff TSS transport and good results (general fit of ± 5%) were observed for simulation over a long time period. The following deposition limited model was used:

$$E = K \cdot Md^{\alpha} \cdot Imax5^{\beta} \cdot VR^{\gamma}$$

E	=	transported mass during any event (kg)
Md	=	available mass (kg)
Imax5	=	maximum intensity within a five-minute time interval (mm/h)
VR	=	runoff volume(m^3)
K, α, β, γ	=	parameters peculiar to each catchment.

The same two-step approach did not provide such satisfactory results for BOD_5 and COD. A one-step approach was then tested with only two control variables. This model was basically different, assuming that available mass is not a limiting factor. Results for COD and BOD_5 were satisfactory (general fit of ± 10%) but not as good as those obtained for TSS.

Transported loads were estimated by the following transport-limited equation:

$$E = K' \cdot Imax5^{\beta'} \cdot VR^{\gamma'}$$

However it must be noticed that COD and BOD_5 computed results are always overestimated for the Maurepas catchment whereas, more generally speaking, the modelling of the observed mass loads for each of the proposed approaches is not very good with respect to small events. Hence, the modelling of pollutant accumulation and transport could be improved either by the introduction of other parameters such as surface type and condition, boundary roughness, in-pipe decay as well as wind speed, humidity, etc. or by a measurement procedure which is better adapted to pollutant sampling.

2.6 Work Done on Pollutants other than TSS, COD and BOD_5

2.6.1 General Statistical Analysis

With respect to correlations existing between the main pollution parameters and other parameters cited in Table 2.5, the general outcome is rather disappointing. The expected high correlations between zinc and TSS or between kjeldahl nitrogen (or total phosphorus) and COD (or BOD_5) are not always significant on each catchment.

The links between the minor pollution parameters and the event characteristics are strong for all the nutrients with the exception of ammonia. Their concentration can be linked to the dry weather duration (particularly in the Paris area) and their loads can also be estimated by the dry weather duration and by either the runoff volume or the amount of rainfall or the maximum flow rate.

No noticeable correlation has been noted as existing between heavy metals and event characteristics.

2.6.2 Highest EMCs and Highest Loads during an Event

For the major part of the minor pollution parameters presented here, the ratio between the maximum concentration and the mean concentration varies from 3 to 5 (depending on the catchment) whereas this ratio varies from 5 to 8 for TSS and 5 to 15 for COD or BOD_5.

The nature of the events which correspond to the highest concentrations or loads is very unsteady and the characteristics of their corresponding rain events are unlikely to explain them. Table 2.5 shows that the highest concentrations and loads are quite homogeneous from one catchment to another.

Table 2.5. Highest EMCs (mg/l) and highest loads (kg) observed during an event for the four experimental French catchments. After le Ministère de l'Urbanisme, du Logement et des Transports (1985).

Indicator	MAUREPAS		LES ULIS		AIX-ZUP		AIX-NORD	
	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)
Pb	0.436	1.89	0.731	0.94	0.835	0.54	1.125	1.71
Hg	0.022	0.02	0.0168	0.013	0.0111	0.075	0.0142	0.067
Zn	0.959	3.91	1.920	2.55	0.908	1.71	1.312	2.09
Cd	0.0449	0.01	0.0177	0.016	0.0054	0.014	0.0073	0.020
Ni	0.0648	0.181	0.0469	0.103	0.0680	0.105	0.059	0.157
Cr	0.021	0.029	0.106	0.039	0.0312	0.011	0.086	0.018
Cu	0.0750	0.146	0.0610	0.111	-	-	-	-
N kjeldahl	10.5	21.9	35.2	31.3	39.6	25.1	32.6	22.5
NH_4^+	5.12	8.6	7.81	13.4	6.77	8.1	1.56	1.92
NO_3^-	14.6	68.7	14.1	44.3	15.0	67.5	15.5	14.8
PO_4^{3-}	5.63	6.34	6.24	5.38	5.98	4.96	4.1	2.27
total P	5.23	6.94	9.85	13.4	3.56	7.02	3.4	5.43
HCs	43.3		66.9		16.0		-	-

(A) Highest EMCs observed during an event (mg/l).
(B) Highest loads observed during an event (kg).

Table 2.6. Estimated annual loads (kg/year) and specific loads (kg/ha/year) for the four experimental French catchments. After le Ministère de l'Urbanisme, du Logement et des Transports (1985).

Indicator	MAUREPAS		LES ULIS		AIX-ZUP		AIX-NORD	
	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)
Pb	11	0.41	13	0.30	9	0.35	16	0.17
Hg	0.13	0.0049	0.10	0.0023	0.27	0.011	0.23	0.0033
Zn	44	1.65	37	0.86	17	0.66	21	0.23
Cd	0.18	0.0067	0.24	0.0056	0.11	0.0043	0.13	0.0014
Ni	1.7	0.064	1.5	0.035	0.90	0.035	1.0	0.011
Cr	0.69	0.026	0.54	0.013	0.17	0.0066	0.26	0.0028
Cu	2.0	0.075	2.3	0.053	-	-	-	-
N kjeldahl	440	16	710	17	300	12	300	3.3
NH_4^+	120	4.5	200	4.6	52	2.0	21	0.23
NO_3^-	620	23	620	14	290	11.0	170	1.8
PO_4^{3-}	150	5.6	130	3.0	53	2.1	30	0.33
total P	110	4.1	210	4.9	66	2.6	60	0.65
HCs	370	14	910	21	-	-	-	-

(A) Annual loads (kg/year).
(B) Specific loads (kg/ha/year).

2.6.3 Estimation of the Annual Polluting Loads

Table 2.6 displays the estimated polluting loads for the four catchments. Missing EMCs have been worked out with the help of derived mathematical relations between the minor parameters and the event main characteristics. The percentage of runoff volume for which concentration measurements are available is generally higher than 60%.

2.7 Conclusion

The quantity and quality of the data collected during the French National Programme allow a modelling approach and a general statistical analysis to be performed. The first conclusions of the programme appear to be similar to those that can be generally found in the literature.

The statistical analysis performed on the main parameters shows:

- for the two catchments situated in the same area, the variables involved in the correlation equations are identical;
- the dry weather duration seems to be a more important variable for the Paris area catchments;
- for the Paris area, it appears that collective housing (Les Ulis) generates two to three times more runoff pollution than individual housing (Maurepas), given the same surface, runoff coefficient and amount of rainfall;
- the annual loads are probably not influenced in a significant way by the hydrological regime (for the same amount of rainfall);
- the maximum mean concentrations seem to be of the order of: 1000 to 4000 mg/l for TSS, 600 to 1300 mg/l for COD, 100 to 400 mg/l for BOD_5.

The housing type does not seem to influence the annual heavy metal loads since these are probably linked to the road traffic density.

The findings from this initial programme are intended to form the basis of future similar programmes. However, this initial work on the data collected can be regarded as providing an excellent basis for a distributional analysis, which is the subject of the remainder of this report.

CHAPTER 3: THE BASIC PROGRAM AND THE FITTING PROCEDURES

3.1 The BASIC Program

In order to test the goodness of fit of distributions to data sets, a program of about 36 000 bytes has been written in BASIC and run on an IBM PC compatible microcomputer (VICTOR VPCII, 640 Kbytes).

This program allows the user to enter data and to store them on files. The operator can then choose the statistical distribution he wants to fit from one of six distributions:

- lognormal with 2 or 3 parameters;
- general extreme value with 2 parameters (Gumbel distribution) or 3 parameters (Fréchet distribution);
- Pearson type 3 with 2 parameters (gamma distribution) or 3 parameters.

Two statistical tests (Kolmogorov-Smirnov and Chi-Squared) are performed for the chosen distribution and for each of the two fitting procedures (method of moments and method of maximum likelihood). ASCII files containing the information to visualise the goodness of fit between the data and the calculated values are created. These files are transfered to the subdirectory LOTUS 1-2-3 and can be graphically displayed. Moreover, printed outputs giving general information about the fitting procedure (parameters, quantitiles) and the statistical tests can be provided.

3.1.1 The Program Inputs

The first choice offered when running the program is either to create a new file or to work with a file previously created:

```
DO YOU WANT :

     -TO CREATE A NEW FILE ---------------------------------------> 1
     -TO WORK WITH AN EXISTING FILE ---------------------------> 2


YOUR CHOICE IS No :?
```

If choice No 1 is chosen then three sets of data can be entered at the same time until the first of the three values entered is "9999" showing that the end of the data set has been reached. In the following example, the values 4, 45 and 56 belong to the same COD set, and the three data sets belong to the same file whose name is "OLD":

```
    DO YOU WANT :

         -TO CREATE A NEW FILE ---------------------------------> 1
         -TO WORK WITH AN EXISTING FILE ------------------------> 2


    YOUR CHOICE IS No :? 1

  ENTER FILENAME:? OLD
  ENTER NAME OF CATCHMENT OR SITE :? AIX-NORD
  VALUES =? 4,50,45
  VALUES =? 45,356,15
  VALUES =? 56,84,31
  VALUES =?
```

If "OLD" was a file already existing (choice No 2) then the following menu would have been immediately displayed. This menu would also have been displayed after the file "OLD" corresponding to choice No 1 was complete:

```
  PARAMETERS AVAILABLE :

       -COD (mg/l)-------------------------> 1
       -S.S. (mg/l)------------------------> 2
       -BOD 5 (mg/l)-----------------------> 3


  CHOOSE PARAMETER DESIRED :?
```

Whatever parameter is chosen, the following menu is displayed:

```
   DISTRIBUTIONS AVAILABLE :
   -------------------------

     * LOGNORMAL WITH 2 PARAMETERS ------------------------------> 1
     * LOGNORMAL WITH 3 PARAMETERS ------------------------------> 2
     * GUMBEL (EV1) ---------------------------------------------> 3
     * FRECHET (EV2) --------------------------------------------> 4
     * PEARSON TYPE 3 WITH 2 PARAMETERS (GAMMA) -----------------> 5
     * PEARSON TYPE 3 WITH 3 PARAMETERS -------------------------> 6

   CHOICE No ?
```

Then the program runs for about 15 minutes. The calculation time depends on the chosen distribution and the size of the data set. Both GEV distributions (Gumbel and Fréchet) have a shorter calculation time. At the end of a calculation period several types of results are available.

3.1.2 <u>The Program Outputs</u>

Two kinds of output are obtained from the program: printouts and ASCII files.

3.1.2.1 Printouts

The first output to be printed is the complete list of the ranked EMC data for a given pollution indicator. The corresponding cumulative probability of each EMC is also displayed. Some statistical parameters of the sample (mean, standard deviation, skewness) are also presented (without any bias correction) on the same printout. An example of such a printout, characterising the data sample, is given in Table 3.1. The size of sample is smaller than the number of events because chemical analyses have not been performed for all the flow events recorded.

Table 3.1. Example of printout from the BASIC program.

```
SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)
----------------------------------------------------------------------

  EVENT MEAN CONCENTRATION OF COD (mg/l)    CATCHMENT : AIX-NORD
       SIZE OF SAMPLE= 50               NUMBER OF EVENTS= 72

----------------------------------------------------------------------
*    48   0.012       62   0.032       63   0.052       65   0.072   *
*    71   0.092       77   0.112       86   0.131       86   0.151   *
*    92   0.171      106   0.191      108   0.211      120   0.231   *
*   120   0.251      121   0.271      127   0.291      130   0.311   *
*   155   0.331      156   0.351      157   0.371      173   0.390   *
*   178   0.410      185   0.430      188   0.450      194   0.470   *
*   199   0.490      204   0.510      208   0.530      211   0.550   *
*   217   0.570      220   0.590      240   0.610      274   0.629   *
*   349   0.649      359   0.669      361   0.689      371   0.709   *
*   396   0.729      416   0.749      428   0.769      487   0.789   *
*   512   0.809      547   0.829      566   0.849      583   0.869   *
*   608   0.888      630   0.908      668   0.928      860   0.948   *
*  1090   0.968     1260   0.988                                     *
----------------------------------------------------------------------
*  *  STATISTICAL PARAMETERS OF THE SAMPLE                            *
*                                                                     *
*   MEAN= 302.64                                                      *
*   STANDARD DEVIATION= 261.761                                       *
*   SKEWNESS= 1.726541                                                *
*   COEFFICIENT OF VARIATION= .8649253                                *
*   SMALLEST VALUE= 48                                                *
*   LARGEST VALUE= 1260                                               *
----------------------------------------------------------------------
```

The second type of printout (Table 3.2) shows general information about the distribution (parameters of the distribution, quantiles) and the goodness of fit (statistical tests, percentage of points within the 90% confidence limits) for both fitting procedures (method of moments and method of maximum likelihood):

Table 3.2. Example of the second type of printout from the BASIC program.

```
DISTRIBUTION :                GUMBEL  (EV1)
==================================================================

   Event Mean Concentration of COD (mg/l)   Catchment : AIX-NORD
-----------------------------------------------------------------

 PARAMETERS CALCULATED BY :

  THE METHOD OF MOMENTS     THE METHOD OF MAX. LIK.

     U= 183.682                 U= 195.762
     ALPHA= 206.1663            ALPHA= 160.2414
-----------------------------------------------------------------
  CHI2 TEST

      CHI2 CALCULATED (MOMENTS)= 18
      CHI2 CALCULATED (MAX. LIK.)= 16.4
      CHI2 90% ( 7  degrees of freed.) = 11.99354
-----------------------------------------------------------------

  KOLMOGOROV-SMIRNOV TEST

    The 1% significance level (i.e. satisfactory fit)= 0.231
    The 5% significance level (i.e. good fit)= 0.192
    The 10% significance level (i.e. very good fit)= 0.173
  THE K.S. TEST STATISTIC (MOMENTS)= 0.168
  THE K.S. TEST STATISTIC (MAX. LIK.)= 0.177
-----------------------------------------------------------------

  PROPORTION OF POINTS WITHIN
   THE 90% CONFIDENCE INTERVAL (METHOD OF MOMENTS) :

         PROPORTION WITH  50  VALUES : 74  %
-----------------------------------------------------------------

  THEORETICAL PERCENTILES

     METHOD OF MOMENTS:


      PERCENTILES (mg/l)      90% CONFIDENCE INTERVAL

                            LOWER VALUE       UPPER VALUE

     Conc.(0.01)=-131.2       -220.1             -42.2
     Conc.(0.05)= -42.5       -115.0              29.9
     Conc.(0.10)=  11.7        -52.1              75.6
     Conc.(0.30)= 145.4         93.5             197.3
     Conc.(0.50)= 259.2        202.8             315.7
     Conc.(0.70)= 396.2        319.9             472.6
     Conc.(0.90)= 647.6        519.2             776.1
     Conc.(0.95)= 796.0        633.8             958.3
     Conc.(0.99)=1132.1        890.7            1373.5

     METHOD OF MAXI. LIKELIHOOD:

     Conc.(0.01)= -49.0
     Conc.(0.05)=  19.9
     Conc.(0.10)=  62.1
     Conc.(0.30)= 166.0
     Conc.(0.50)= 254.5
     Conc.(0.70)= 361.0
     Conc.(0.90)= 556.4
     Conc.(0.95)= 671.7
     Conc.(0.99)= 932.9
-----------------------------------------------------------------
```

3.1.2.2 The ASCII Files

Two ASCII files are created and stored for each calculation period and hence for each distribution. The first file contains information about the graphical goodness of fit with the fitting procedure being the method of moments. The second file contains the same kind of information but the fitting procedure is the method of maximum likelihood. For each file the information is stored according to the following structure:

- the first column contains the values of the reduced variates corresponding to the ranked EMCs;
- the second column contains the values of the corresponding ranked EMCs;
- the third column contains the corresponding values of the lower confidence limits;
- the fourth column contains the values of the calculated EMCs corresponding to the plotting positions;
- the fifth column contains the values of the higher confidence limits.

The files corresponding to the method of moments have the name of the distribution finishing with "1" (LOG2P1.PRN, LOG3P1.PRN, GUMBEL1.PRN, PEARSON1.PRN, GAMMA1.PRN, FRECHET1.PRN) whereas the files corresponding to the method of maximum likelihood have a name finishing with "2" (LOG2P2.PRN, LOG3P2.PRN,...).

Those files, at the end of a calculation period, can be transfered through MS-DOS to the subdirectory LOTUS 1-2-3 and can be displayed as graphs. Examples of such graphs are given in Section 4.4.

3.1.3 The Program Organisation

The general organisation of the program can be visualised by the following flow chart (Figure 3.1):

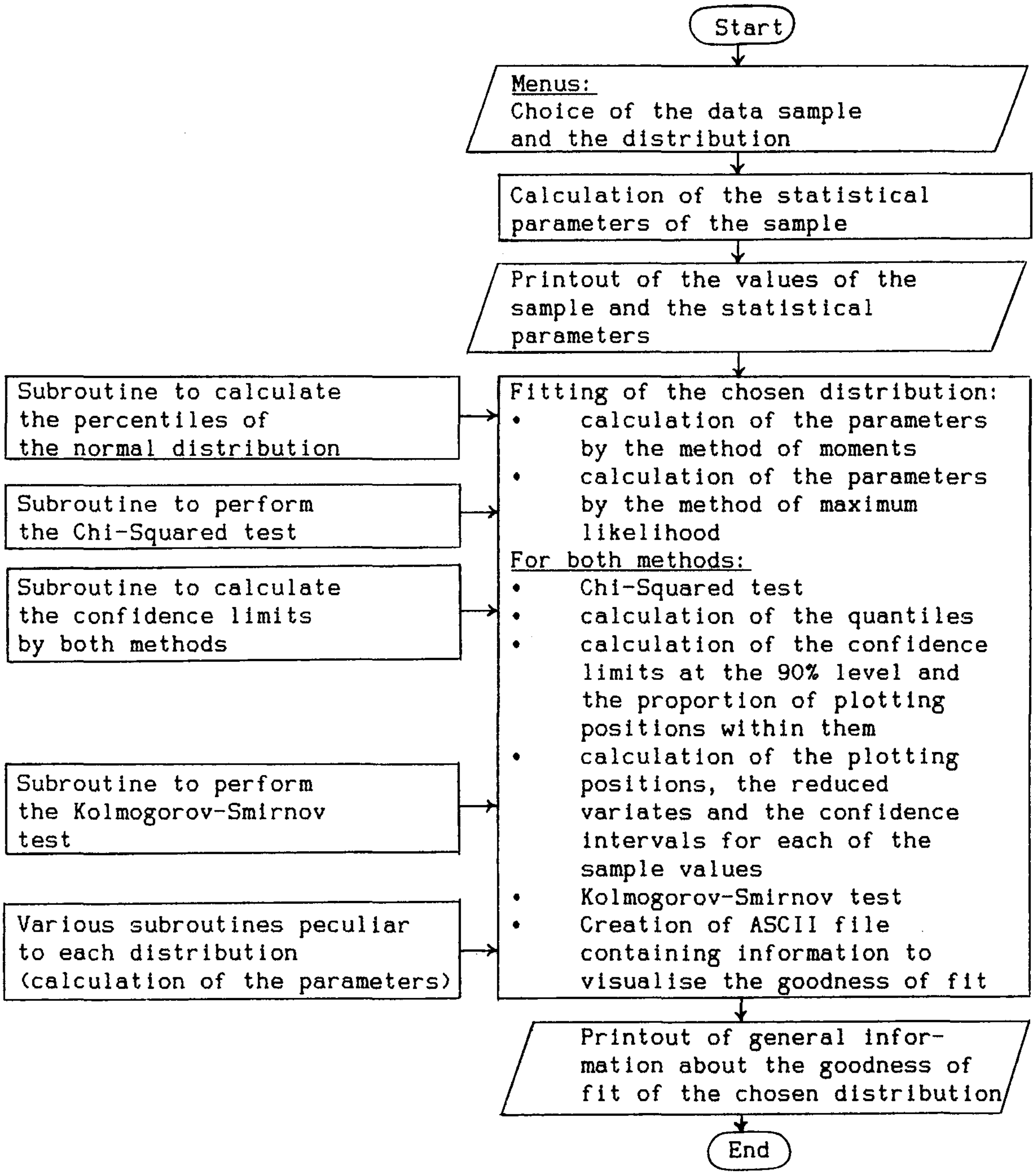


Figure 3.1. Flow chart of the BASIC program.

3.2 The Fitting Procedure

3.2.1 Notion of Statistical Distribution and Reduced Variate

The EMCs from a given catchment and for a given pollutant are considered to be drawn randomly from the same population over a period of time varying from 12 to 16 months. A random variable is characterised by its probability distribution. Two ways of describing a probability distribution are currently used:

- the distribution function $F(x)$ (or cumulative density function) which is the probability that the variate value of a unit drawn randomly from the population is less or equal to x:

  $F(x) = \text{prob}(X \leq x)$

  $f(x)$ is the derivative of $F(x)$ and is called the probability density function (pdf) which is the probability of obtaining x at random from the population:

  $f(x) = dF(x)/dx$

- the linear relation between the variate x and another variate y:

  $x = a + by$

  where a and b are the location and scale parameters of the x distribution. The variable y, which is called the standardised or *reduced variate* with respect to x, has location and scale parameters equal to 0 and 1 respectively. If $G(y)$ is the cumulative density function of y, then we can write:

  $F(x) = G(y)$

Figure 3.2 shows the difference between the plots of $F(x)$ and x versus y. The advantage of this last plot is that the goodness of fit between the straight line (theoretical distribution) and the individual points (plotting positions) is more easily visualised (see Section 3.2.2).

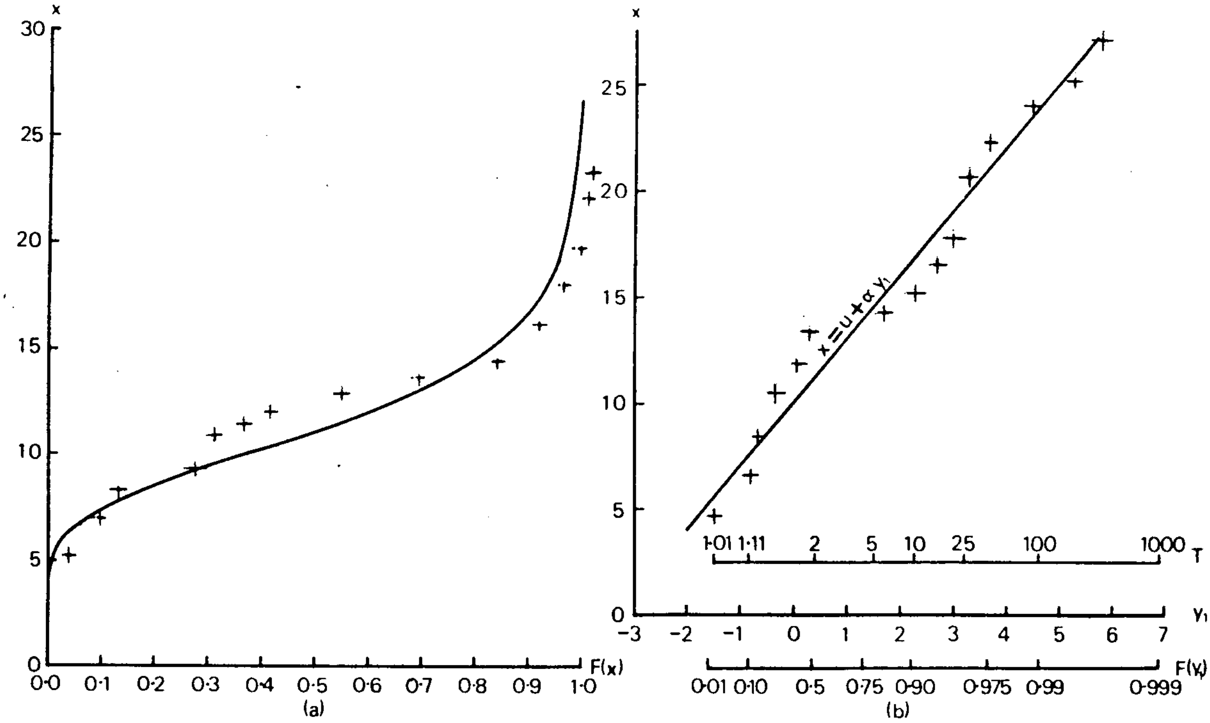


Figure 3.2. An EV1 variate x shown as a function of (a) its own df which itself may be considered as a variate distributed between 0 and 1 and (b) an EV1 reduced variate y. After Flood Studies Report (NERC, 1975).

3.2.2 The Graphical Comparison between the Plotting Positions and the Theoretical Distribution Fitted

Since x is a random variable, $y(x)$ or $F(x)$ should ideally be chosen such that the values of x lie on the population line. For each ranked value x_i ($x_1 \leq x_2 \leq \ldots x_i \leq \ldots x_n$) a cumulative probability F_i is calculated by a general formula:

$$F_i = (i - \alpha) / (N + 1 - 2\alpha)$$

where i = rank

N = size of sample

α = coefficient depending upon the type of distribution.

The plotting of x_i versus F_i or x_i versus y_i gives the *plotting positions* of the sample. For example the plotting positions are represented by the individual points on Figure 3.2. Because x_i is random, its probability of falling on the population x/y line is almost negligible but y can be specified so that the mean of x_i, $E(x_i)$, when plotted, lies on the population line (Figure 3.3).

Such a plotting position is unbiassed because, on average, the plotted x_i indicates the population line.

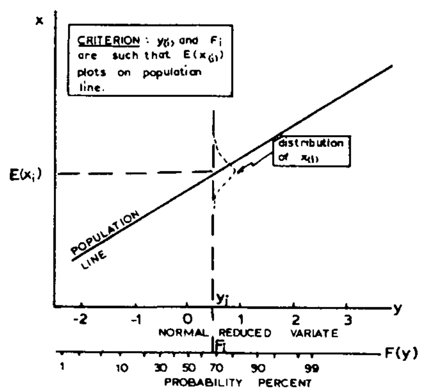


Figure 3.3. Illustration of plotting position criterion, after Cunnane (1978).

Typical values of α are proposed in the literature to obtain unbiassed plotting positions. Table 3.3 summarises the typical formulae that have been used in this study .

Table 3.3. Plotting positions for samples drawn from specific statistical distributions. After Cunnane (1978).

Distribution	Proponent of plotting positions formula	Value of α	Plotting probability F_i
Lognormal (2 or 3 parameters)	Blom (1958)	3/8	$(i - 3/8) / (N + 1/4)$
GEV (2 or 3 parameters)	Gringorten (1963)	0.44	$(i - 0.44) / (N + 0.12)$
Pearson Type 3 or gamma		2/5	$(i - 2/5) / (N + 1/5)$

Once the plotting positions and the theoretical distribution are plotted on the same graph (see Fig. 3.2), one can judge the goodness of fit between them by several means:

- by computing the correlation coefficient between x and y;
- by computing the ideal least squares fitting straight line and comparing it with the actual theoretical distribution line;
- by eye.

In this study, given that two statistical tests have been used to evaluate the goodness of fit, a comparison by eye has been adopted.

3.2.3 The Statistical Tests

The χ^2 and Kolmogorov-Smirnov goodness of fit indices express the agreement between an observed sample of data and some theoretically specified population. The index is a sample statistic having a distribution. If the observed index value lies in the tail of its sampling distribution, doubt is thrown on the original hypothesis that the sample comes from the theoretically specified distribution. These two statistical tests are the most commonly used tools to estimate the goodness of fit of statistical distributions.

Although these tests are not often used as tools to select the best distribution among a set of distributions, it is admitted that the lower the index, the closer the sample is to the theoretical distribution under test. Hence, the lowest index corresponds to the best fitted distribution.

3.2.3.1 The Kolmogorov-Smirnov Test

This test is based on the difference between the empirical distribution (plotting positions) $S_N(x)$ and the distribution function under test $F(x)$. Figure 3.4 shows those distributions plotted for a specific example.

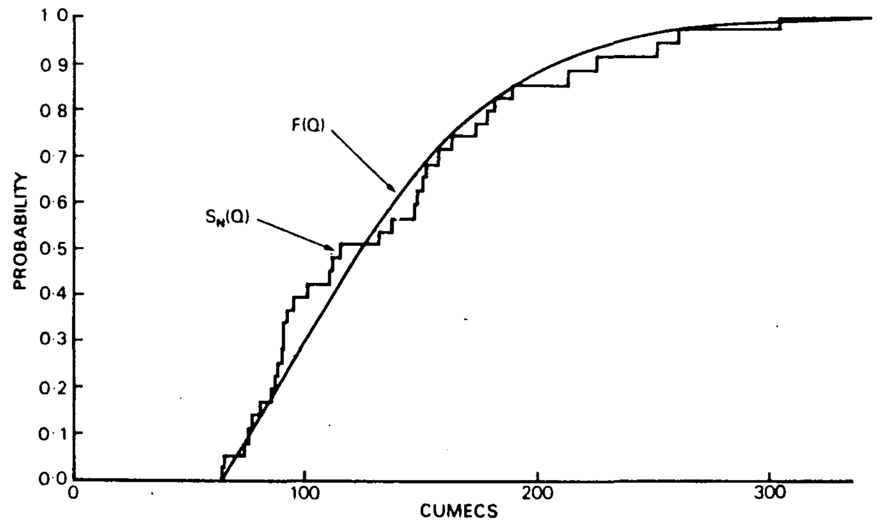


Figure 3.4 Empirical distribution function $S_N(Q)$, and fitted EV1 distribution function $F(Q)$. After NERC (1975).

The empirical distribution function $S_N(x)$ is defined by:

$$S_N(x) = \frac{\text{rank}(x)}{N}$$

At each observed x_i value, the difference between $F(x_i)$ and $S_N(x_i)$ has two values as $S_N(x)$ changes at each such value of x. Denote these two values which are illustrated in Figure 3.5 by δ^+ and δ^-.

$$\delta^+ = \frac{\text{rank }(x_i)}{N} - F(x_i)$$

$$\delta^- = F(x_i) - \frac{\text{rank }(x_{i-1})}{N}$$

Let $d_i = \max(\delta^+, \delta^-)$

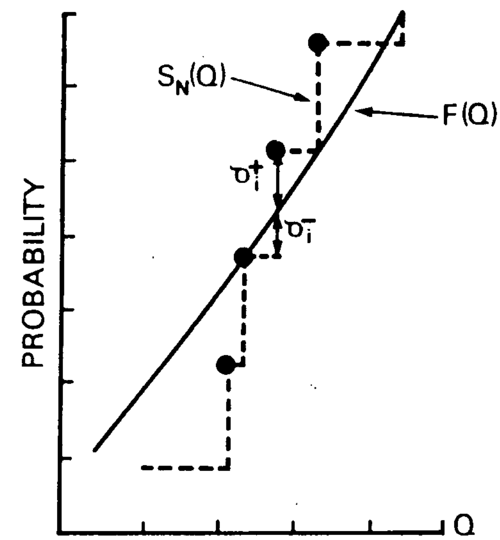


Figure 3.5 Illustration of the two distinct differences, δ^+ and δ^- between $F(Q)$ and $S_N(Q)$ at each data point as used in Kolmogorov-Smirnov test. After NERC (1975).

The maximum value of all the d_i values is the Kolmogorov-Smirnov goodness of fit index, D_N:

$$D_N = \max(d_1,\ d_2,\ \ldots\ d_N)$$

- For $20 < N < 35$:

if $D_N \geqslant 1.483\ (N^{-0.4793})$ the distribution under test is rejected at the 10% level of confidence;

if $D_N \geqslant 1.1097\ (N^{-0.4445})$ the distribution under test is rejected at the 5% level of confidence;

if $D_N \geqslant 0.9196\ (N^{-0.4175})$ the distribution under test is rejected at the 1% level of confidence.

- For $N > 35$:

  if $D_N \geq 1.07/N^{1/2}$ the distribution under test is rejected at the 20% level of confidence;

  if $D_N \geq 1.22/N^{1/2}$ the distribution under test is rejected at the 10% level of confidence;

  if $D_N \geq 1.36/N^{1/2}$ the distribution under test is rejected at the 5% level of confidence;

  if $D_N \geq 1.63/N^{1/2}$ the distribution under test is rejected at the 1% level of confidence.

If the observed value of D_N does not exceed the critical value at the 10% level of confidence, then the fit is considered to be very satisfactory. This test involves only one value (measuring the maximum "distance" between the empirical distribution and the theoretical distribution) to evaluate the goodness of fit.

3.2.3.2 The χ^2 Test

This test compares the size E_j of each class of the theoretical pdf(x) = f(x) with the size O_j of each class of the sample histogram according to the following formula:

$$\chi^2 = \sum_{j=1}^{K} \frac{(E_j - O_j)^2}{E_j}$$

where K = total number of classes

In this study $O_j = 5$ for the first (K-1) classes and $5 < O_j < 10$ for the last class.

The above quantity is distributed as χ^2 with (K-1-number of parameters estimated) degrees of freedom.

The quantity $(E_j - O_j)$ is an obvious parameter to be used as an index because large values of this quantity indicate poor agreement between sample and distribution.

When the distribution being tested has been fitted to the sample, the degrees of freedom are reduced by the number of parameters estimated.

If we set the hypothesis H_0: the distribution fits the data at the α% level of confidence then we compare the computed value of χ^2 with the values in χ^2 tables given for acceptance levels and number of classes. If χ^2 (computed) > χ^2 (K - 1 - number of parameters estimated) then we reject H_0 at the α% level of confidence.

In contrast to the Kolmogorov-Smirnov test, the χ^2 test takes into account the distribution as a whole to evaluate the index.

Figure 3.6 gives a graphical interpretation of the χ^2 test.

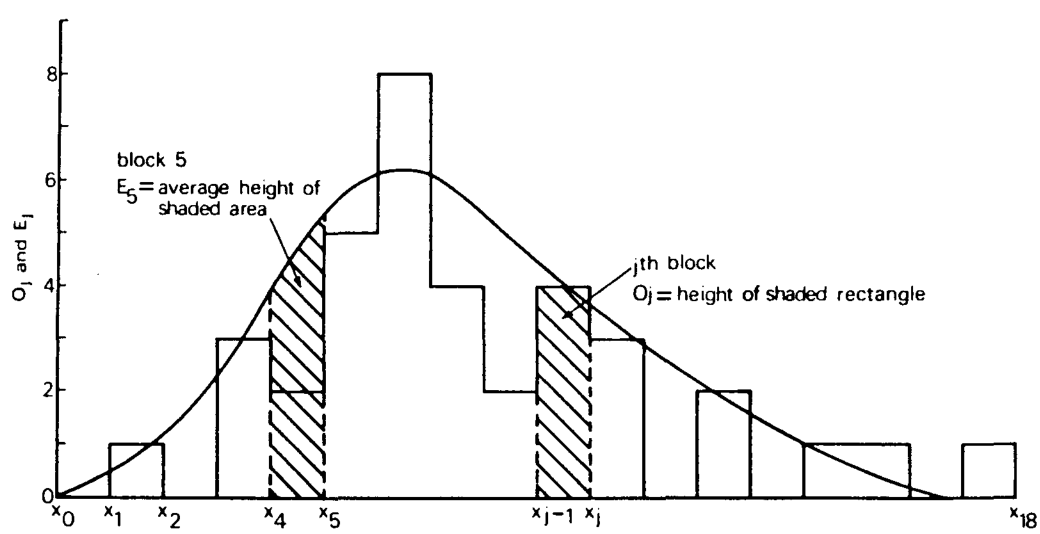


Figure 3.6 A sample histogram with a theoretical pdf superimposed on it and illustrating the notation E_j and O_j. After NERC (1975).

3.2.4 The Confidence Limits of Quantiles

Given a random variable x, the probability for x to be lower than the numerical value of x_p is:

$$\text{prob } (x \leq x_p) = F(x_p) = p$$

The numerical value of x corresponding to a non-exceedance probability p, is called a *quantile* x_p.

The estimation of a quantile x_p is done by calculating the parameters of a given distribution. For the method of moments those parameters are estimated with the use of the sample basic statistics (mean, standard deviation, skewness) whereas for the maximum likelihood estimation, other statistics are required. Therefore the estimation of x_p varies with the sample. Hence x_p can be considered as a random variable whose value depends upon the sample drawn from a population.

To compute the confidence interval of a quantile one must know the sampling distribution of the variable x_p. The simulation work undertaken by Kite (1975) has shown that the sampling distributions of the variable x_p is very close to that of the normal distribution. Hence the bounds of the confidence interval are calculated with the following general formula:

$$x_p \pm U_{(1-\alpha/2)} \cdot \sigma_{x_p}$$

where $U_{(1-\alpha/2)}$ = standard normal variable at the $(1-\alpha/2)$ level of confidence

σ_{x_p} = estimate of the standard error of the quantile x_p.

Figure 3.7 illustrates the distribution of a standard normal variable.

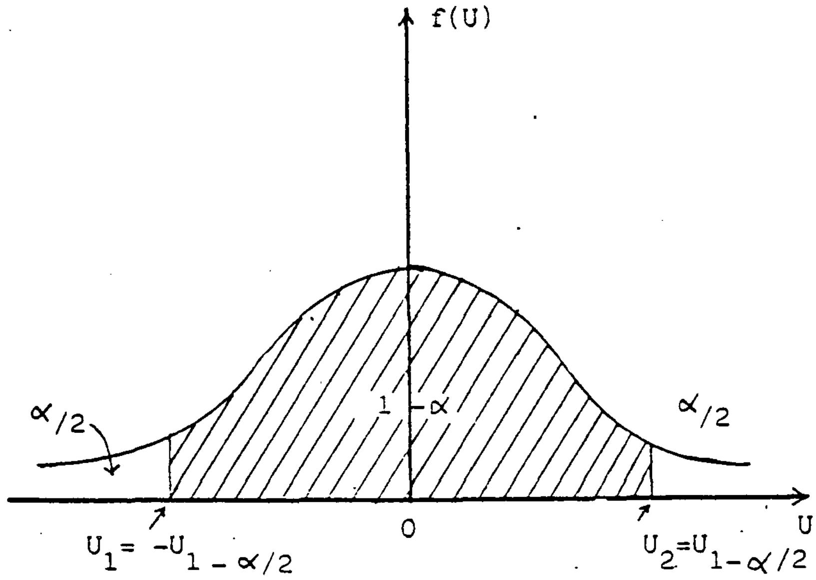


Figure 3.7 Distribution of a standard normal variable.

When plotting the upper and lower confidence limits of the theoretical quantiles, some measure of precision can be placed on the estimated quantiles. An example of this concept is given in Figure 3.8. Line AB corresponds to some arbitrary cumulative probability distribution and instead of the return period *x* axis the author could have employed a cumulative probability scale.

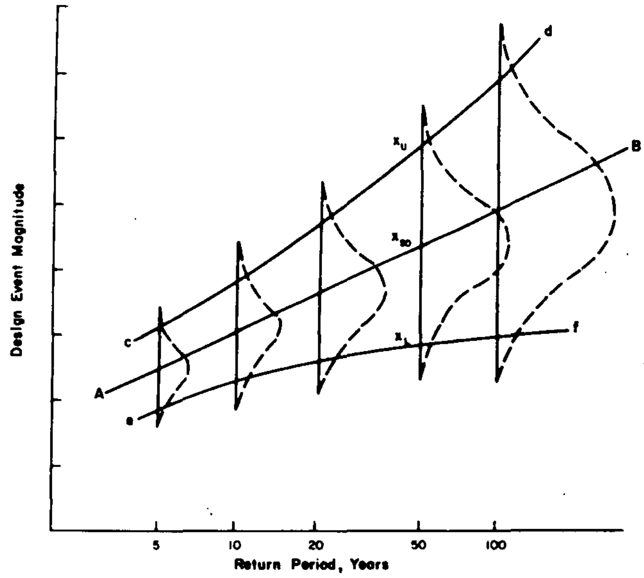


Figure 3.8 Confidence limits for design events. After Kite (1975).

The plotting positions could also have been displayed on Figure 3.8. The percentage of plotting positions situated within the confidence limits is an indicator of goodness of fit. The higher the percentage the better the fit is.

3.2.5 The Fitting Methods

When a random sample of data is available from a population whose distribution is unknown, then the primary objective is to work out the parameters of each distribution (characterised by its own equation) using a method of fitting. The two main methods of fitting that are in current use are the method of moments and maximum likelihood.

3.2.5.1 The Method of Moments

The principle of the method of moments is that if all the moments of a distribution (mean, variance, skewness, etc.) are known, then the distribution is known. In the distributions used in this work, the number of moments needed to calculate the parameters equals the number of parameters of the distribution. In a two parameter distribution, the first two moments (mean and variance) are sufficient to specify the distribution. The location parameter is dependent on the first moment whereas the scale parameter is dependent on the standard deviation. The third parameter, known as the shape parameter, depends on the skewness. Of course, the assumption has been made that the distribution of variate values in the sample is a good estimate of the population distribution and unbiassed estimates of the population characteristics are to be used. The three first unbiassed moments used are presented here:

mean : $$\mu_1 = \frac{1}{N} \sum_{i=1}^{N} x_i$$

variance: $$\mu_2 = \frac{1}{N-1} \sum_{i=1}^{N} (x_i - \mu_1)^2$$

$$\text{skewness:} \quad \hat{g} = \frac{\hat{\mu}_3}{(\hat{\mu}_2)^{3/2}} \quad \text{with} \quad \hat{\mu}_3 = N \sum_{i=1}^{N} (x_i - \hat{\mu}_1)^3$$

3.2.5.2 The Method of Maximum Likelihood

If we call "A" the set of parameters of the distribution to be estimated and x the sample values x_i then PR(x|A) is the probability of drawing the observed random sample x from a population with parameters A. In the expression PR(x|A) the variable is A. Define a new expression L(x|A) where x is the variable :

$$L(x|A) = \prod_{i=1}^{N} f(x_i|A)$$

f(x|A) is the pdf and L(x|A) is called the *likelihood* of A given the observed sample x. The maximum likelihood principle is based on the attempt to find the set of parameters A which maximises the likelihood function L(x|A). In other words, the maximum likelihood estimates of the parameters make the given sample most likely or probable.

This method of fitting is generally preferred to the method of moments by most modern statisticians because it is generally more efficient although it is more difficult to compute . Convergence problems may appear during the computation.

3.2.6 The Mixture of Distributions

Some statistical distributions to be fitted to observed data can be expressed as superpositions of two or more single distributions. Such superpositions are termed *mixture of distributions*.

If $f(x, p, \sigma, \mu)$ is the mixture of C distributions of the same kind $g_i(x, \sigma_i, \mu_i)$ then we can write the equality :

$$f(x,\ p,\ \sigma,\ \mu,) = \sum_{i=1}^{c} p_i\ g_i\ (x,\ \sigma_i,\ \mu_i)$$

where p_i is the mixing proportion of each distribution:

$$\sum_{i=1}^{c} p_i = 1.$$

The example given in Figure 3.9 illustrates the mixture of 2 normal distributions.

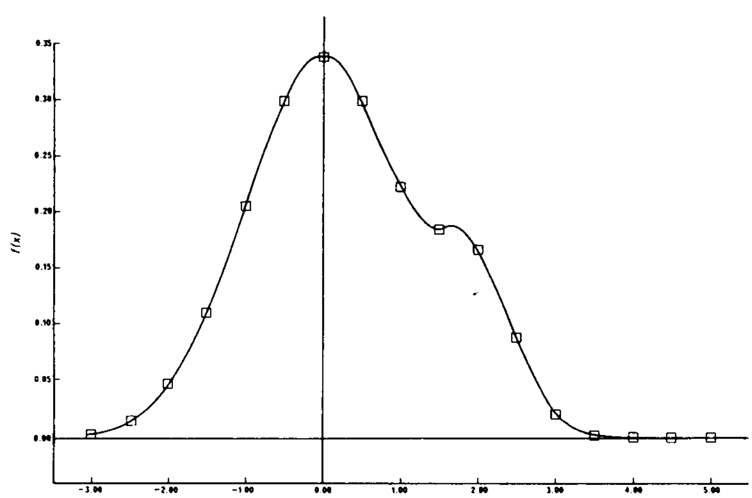


Figure 3.9 Mixture of two univariate normal densities. After Everitt and Hand (1981).

The case of mixed distributions is presented here, although it has not been considered in this report. Such mixture of population inputs could be expected to occur in an EMC data sample.

It is known that under particular hydraulic conditions suspended solids up to a given diameter and density are likely to be removed within the pipe whereas other larger diameters would not be affected. Over a sufficiently long period of time one can end up with a set of TSS EMCs (or other pollutants linked to them such as COD, BOD_5...) presenting the characteristics of two or more mixed populations. Deciding on the number of mixed distributions is not a simple problem to deal with and little work has been done on this subject. The study of the sample histograms is an obvious approach. However unimodality of a distribution does not imply a single distribution just as multimodality does not imply a mixture. Nevertheless histograms have been constructed for each pollutant and each catchment. They are displayed in Chapter 4.

3.3 The Statistical Distributions Used

The six distributions presented in this section have a common positive skewness. Most of the following presentation has been drawn from the Flood Studies Report (NERC, 1975) and from the Laboratoire d'Hydrologie Mathématique (Montpellier, France) internal publications of J.M. Masson, (1982, 1983, 1985). Only general information about the distributions is presented in this section. Further developments about fitting procedures for both the method of moments and maximum likelihood as well as details concerning the calculation of quantiles and confidence intervals are included in the appendices.

3.3.1 The Lognormal Distribution

3.3.1.1 Theoretical Basis

The lognormal distribution has been mostly used when dealing with EMC data because, being related to the normal distribution, it is fairly easy to apply and to compute. However there could be a theoretical basis to its successful application. For example, Chow (1954) stated that the annual maximum flood would be lognormally distributed if it is assumed that it is the product of a large number of random effects. As a matter of fact the central limit theorem states that the sum of lognormally distributed random variables is normally distributed. However, as stated in the Flood Studies Report (NERC, 1975), to be valid as a deductive theory, this property would have to be identifiable. Failing this, the distribution can only be supported by empirical data. However storm runoff quality can be considered as the product of random processes. The lognormal distribution is therefore probably the most suitable theoretically based distribution meant to fit EMC data.

3.3.1.2 Definition and Characteristics

The variable x follows a lognormal distribution when the variable $z=\ln(x-x_o)$ follows a normal distribution with x_o being the third parameter of a three parameter distribution.

The probability density function of x is:

$$f(x) = \frac{1}{\sqrt{2\pi}} \cdot \frac{1}{\beta} \cdot \frac{1}{(x - x_o)} \cdot e^{\frac{-\frac{1}{2}(\ln(x - x_o) - \alpha)^2}{\beta}}$$

α is the scale parameter ($\alpha = \mu_z$)

β is the shape parameter ($\beta = \sigma_z$)

x_o is the location parameter ($x_o = 0$ for a two parameter lognormal distribution).

The cumulative probability density function is defined as:

$$F(x) = \int_0^x f(x) \cdot dx$$

The plotting position formula used is the Blom formula:

$$F_i = (i - 3/8)/(N + 1/4)$$

Appendix 3.1 provides details about the fitting procedures and the confidence interval for the two and three parameter lognormal distributions.

3.3.2 The General Extreme Value Distribution

3.3.2.1 Theoretical Basis

The statistical theory of the extreme value was developed in the 1920's by Fisher et. al. (1928) and was promulgated by Gumbel (1935, 1937) during the 1930's. Gumbel tested the theory by fitting the type 1 distribution (2 parameters) to long flow records and stated that the extreme value theory was supported by sufficient evidence.

As described in the NERC Flood Studies Report (1975), "Extreme values theory implies that if the random variable Z is the maximum in a sample of size N from some population of x value, then provided N is sufficiently large, the distribution of Z is one of three limiting types, the choice depending on the distribution of x ". But so far, the theoretical basis has been doubted, since firstly, daily flows cannot be considered to be statistically independent and, secondly, mean and variance of the daily flow have been shown to vary with season (Quimpo, 1967). Besides, the theory is not helpful when choosing types of extreme value distribution.

With respect to the EMCs values, although they are assumed to be independent, they are unlikely to fit the extreme value theory. Nevertheless two types are tested in this work (type 1 and type 2) assuming that the theoretical basis is not convincing or restricting enough.

3.3.2.2 Definition and Characteristics

Each of the three types of extreme value (EV) distribution is characterised by the value of the parameter k. If k is negative it corresponds to type 2 (known as EV2 or Fréchet distribution), k positive corresponds to type 3 (EV3) and k equal to zero corresponds to type 1 (EV1 or Gumbel distribution). Type 2 and type 3 are three parameter distributions whereas type 1 needs two parameters to be defined. A property to be noticed is that if x follows the Fréchet distribution then ln (x) follows the Gumbel distribution.

The general formulation of a three parameter EV probability density function is:

$$f(x) = \frac{1}{\alpha} \cdot (1 - k(x-u)/\alpha)^{1/k-1} \cdot e^{-[1-k(x-u)/\alpha]^{1/k}}$$

The cumulative density function is:

$$F(x) = \exp(-[1-k(x - u)/\alpha]^{1/k})$$

with:

α = scale parameter
u = location parameter
k = shape parameter.

Figure 3.10 shows, as an example, how the different values of k are related to each other.

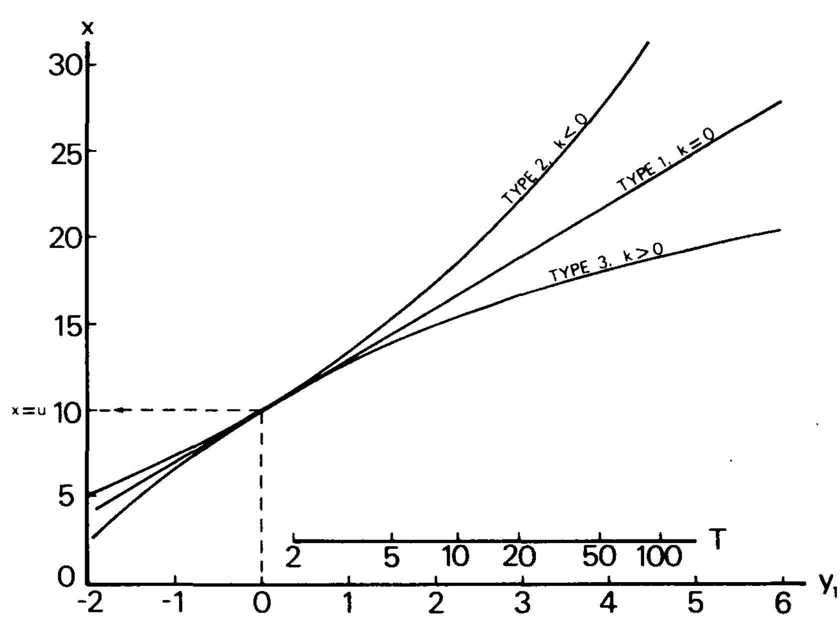


Figure 3.10 The three types of extreme value variate shown as functions of the type 1 reduced variate by the relation $x=u+\alpha(1-\exp(-ky_1))/k$. After Natural Environment Research council (1975).

Figure 3.11 shows an interesting property of the EV distribution. An empirical way of determining which type of distribution could be applied to a sample is to work out its skewness. Then, using the relationship between g and k, one can decide which type to use.

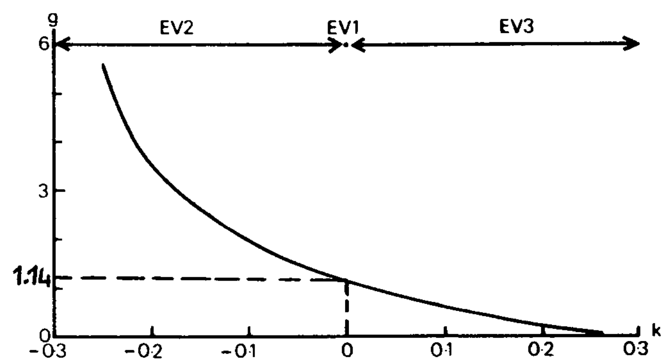


Figure 3.11 Skewness g of extreme value variates as a function of the shape parameter k. After Natural Environment Council (1975).

Since all the samples of EMCs present a skewness higher than 1.14, the Fréchet distribution has been tested upon them as well as the Gumbel distribution.

Appendix 3.2 gives further details about fitting procedures.

3.3.3 The Pearson Type 3 Distribution

3.3.3.1 Theoretical Basis

Pearson sought a family of distributions that could satisfactorily represent observed data. The Pearson Type 3 distribution is a particular case drawn from this family built on the limiting case of the hypergeometrical distribution. The curves representing those functions are usually unimodal and have a smooth contact with the x-axis when reaching the limit $f(x)=0$, for a given value of x. In the case of the Pearson type 3 distribution, the curve is J shaped when the parameter γ (see section below) is less than or equal to 0.

3.3.3.2 Definition and Characteristics

The Pearson Type 3 distribution has three parameters denoted by x_o, β and γ. When $\gamma=1$ a special case gives the exponential distribution whereas $x_o=0$ gives the gamma distribution. The cases of $x_o=0$ and $x_o\neq0$ have been considered in this report.

The general formulation of the probability density function is:

$$f(x)=\frac{1}{\beta^{\gamma}\Gamma(\gamma)} \cdot (x-x_o)^{\gamma-1} \cdot e^{\frac{-(x-x_o)}{\beta}}$$

where $\Gamma(\gamma)$ is the complete gamma function.

the cumulative probability function is: $F(x)=\int_{x_o}^{x} f(x).dx$

β is the scale parameter, γ is the shape parameter and x_o is the location parameter.

The plotting positions can be obtained by the compromising formula:

$$F_i = \frac{i - 2/5}{N + 1/5}$$

The reduced variate y is related to x such that $F(x) = G(y)$ $y=(x-x_o)/\beta$ and $g(y) = \frac{y^{\gamma-1} \cdot e^{-y}}{\Gamma(\gamma)}$

Details about the fitting procedures and confidence interval calculations are provided in Appendix 3.3 for both Pearson Type 3 and gamma distributions.

CHAPTER 4: INTERPRETATION OF THE RESULTS

The outcome of the computational analysis provides several types of information for six selected pollution parameters:

- general information about the shape of the EMC distribution. These results are drawn from basic statistics such as histogram plots, coefficients of variation and skewnesses;

- the comparison of significance testing such as the Kolmogorov-Smirnov and χ^2 indices for all the distributions and for six pollution parameters enables an identification of the most appropriate distribution sets and fits.

4.1 The Shape of the EMC Distributions

4.1.1 The Frequency Plots

The histograms for the EMCs in respect of COD, BOD_5, TSS, Zinc, $N\text{-}NH_4^+$ and NO_3^- are presented in Figure 4.1 to 4.4. The x axis gives the centres of classes (in mg/l) whilst the y axis represents the number of events per class.

As expected all the histograms show that the pollutant distributions are clearly positively skewed. Some of the distributions such as the TSS at Maurepas or the COD and BOD_5 for Aix-Nord possess a secondary peak suggesting that two separate distributions could be mixed.

In the case of the Les Ulis catchment, it seems that the suspected presence of foul water in the separate drainage system is confirmed by the plot of the histograms for COD and $N\text{-}NH_4^+$. Secondary peaks are apparent for both COD and $N\text{-}NH_4^+$, being particularly well pronounced in the latter case and together with the persistent occurrence of high ammonia levels, reflects foul wastewater contamination. It should be borne in mind however that the $N\text{-}NH_4^+$ data set for Les Ulis is relatively small consisting only of a total of 47 values.

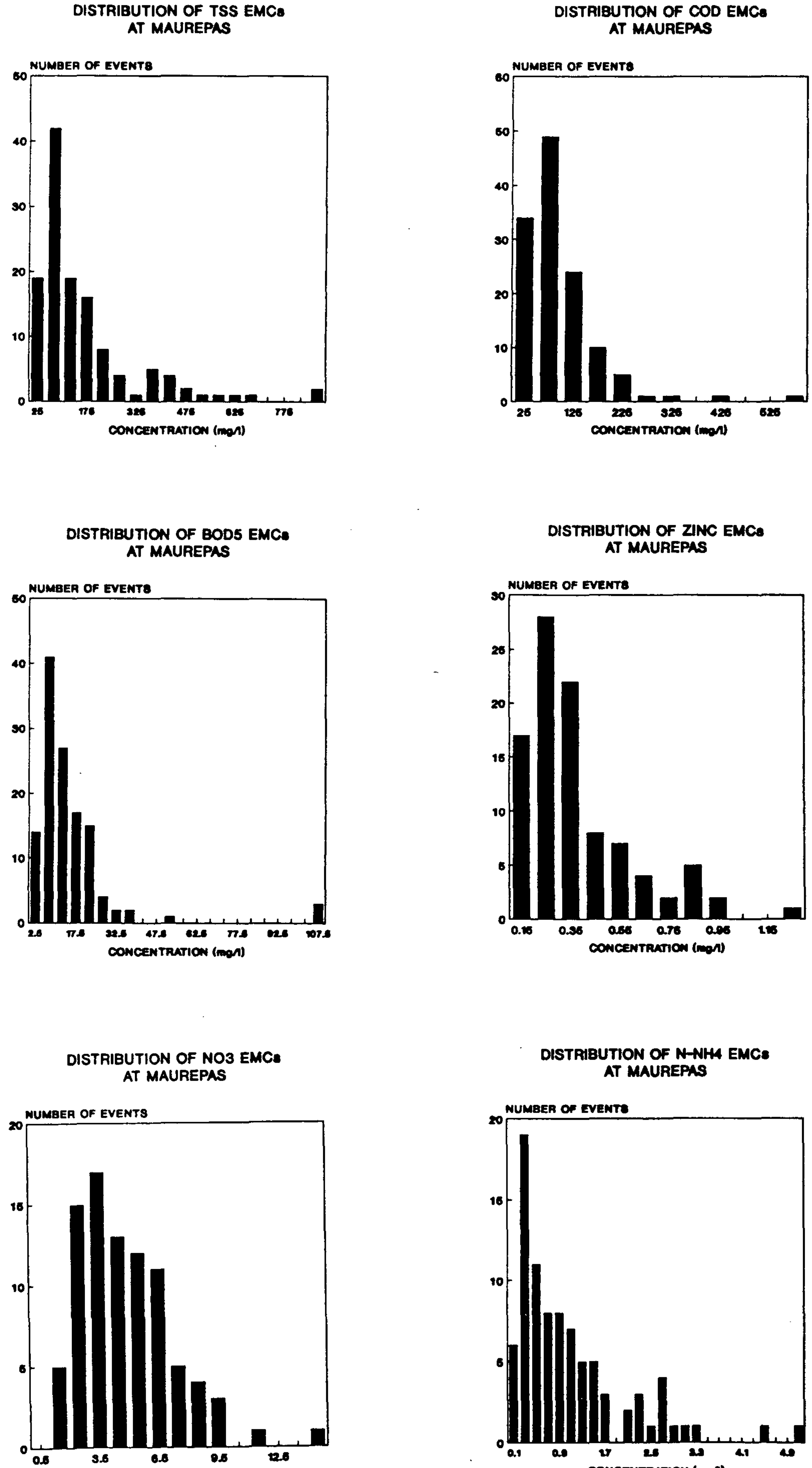


Figure 4.1 EMC histograms of the pollution parameters from the Maurepas catchment.

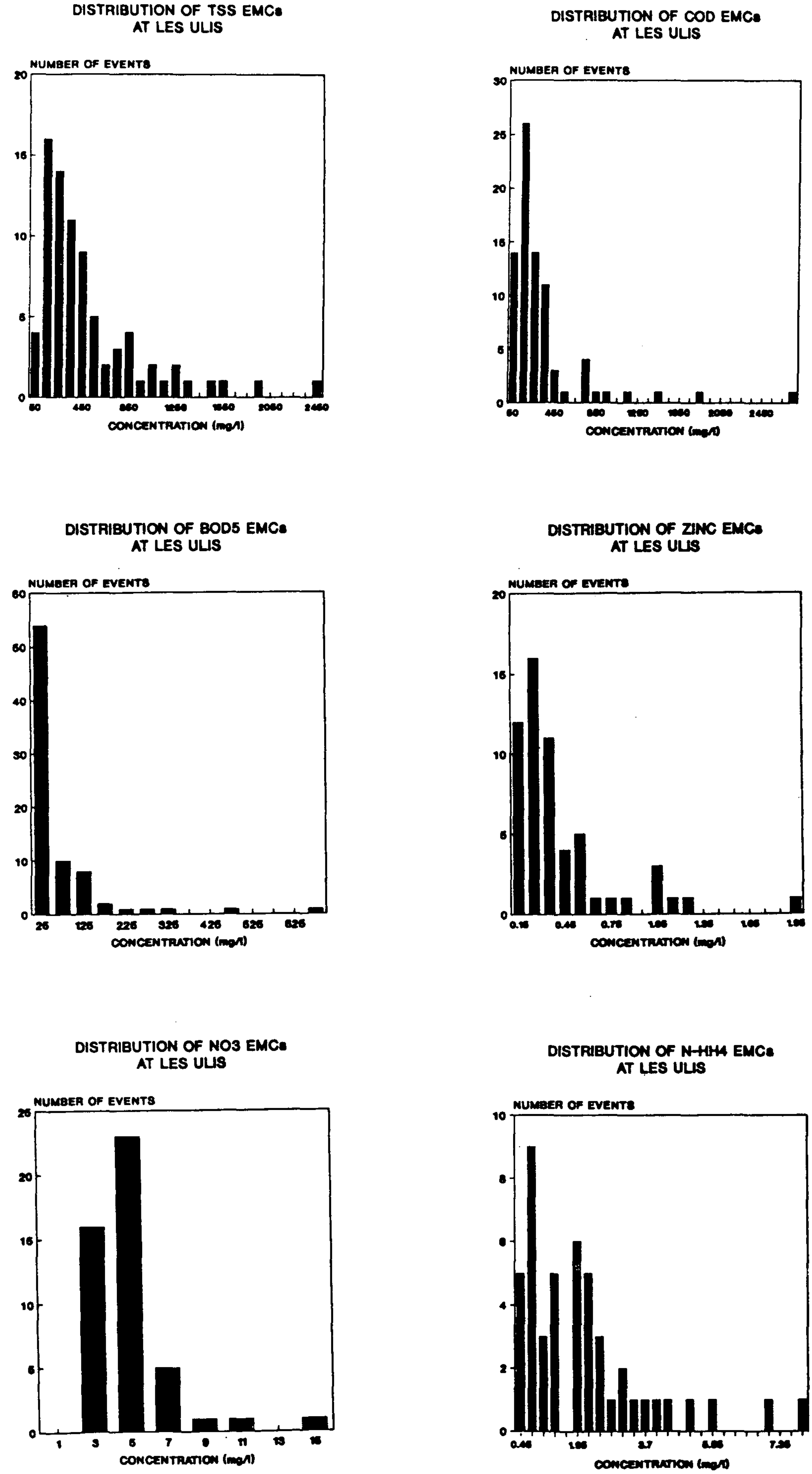


Figure 4.2 EMC histograms of the pollution parameters from the Les Ulis catchment.

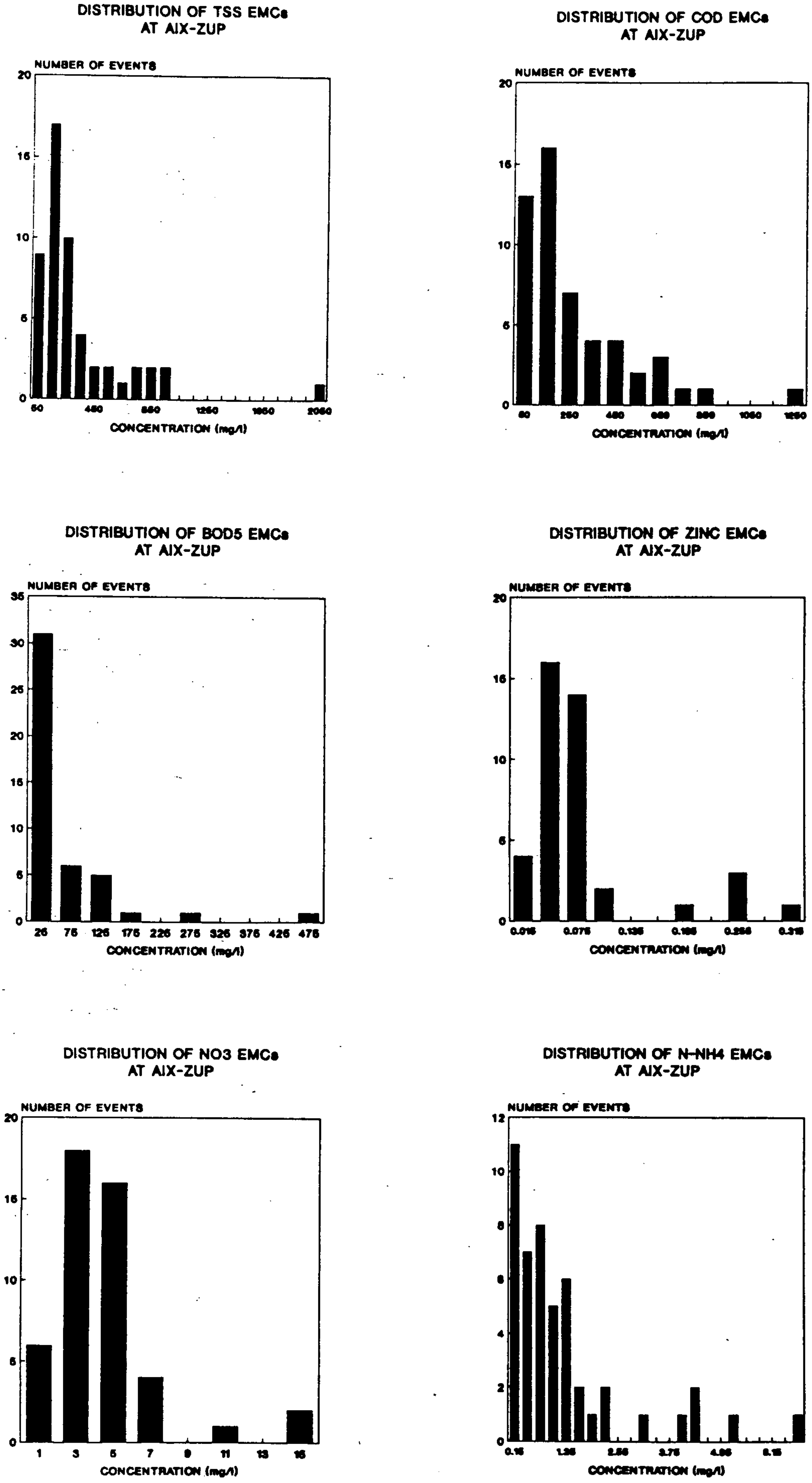


Figure 4.3 EMC histograms of the pollution parameters from the Aix-Zup catchment.

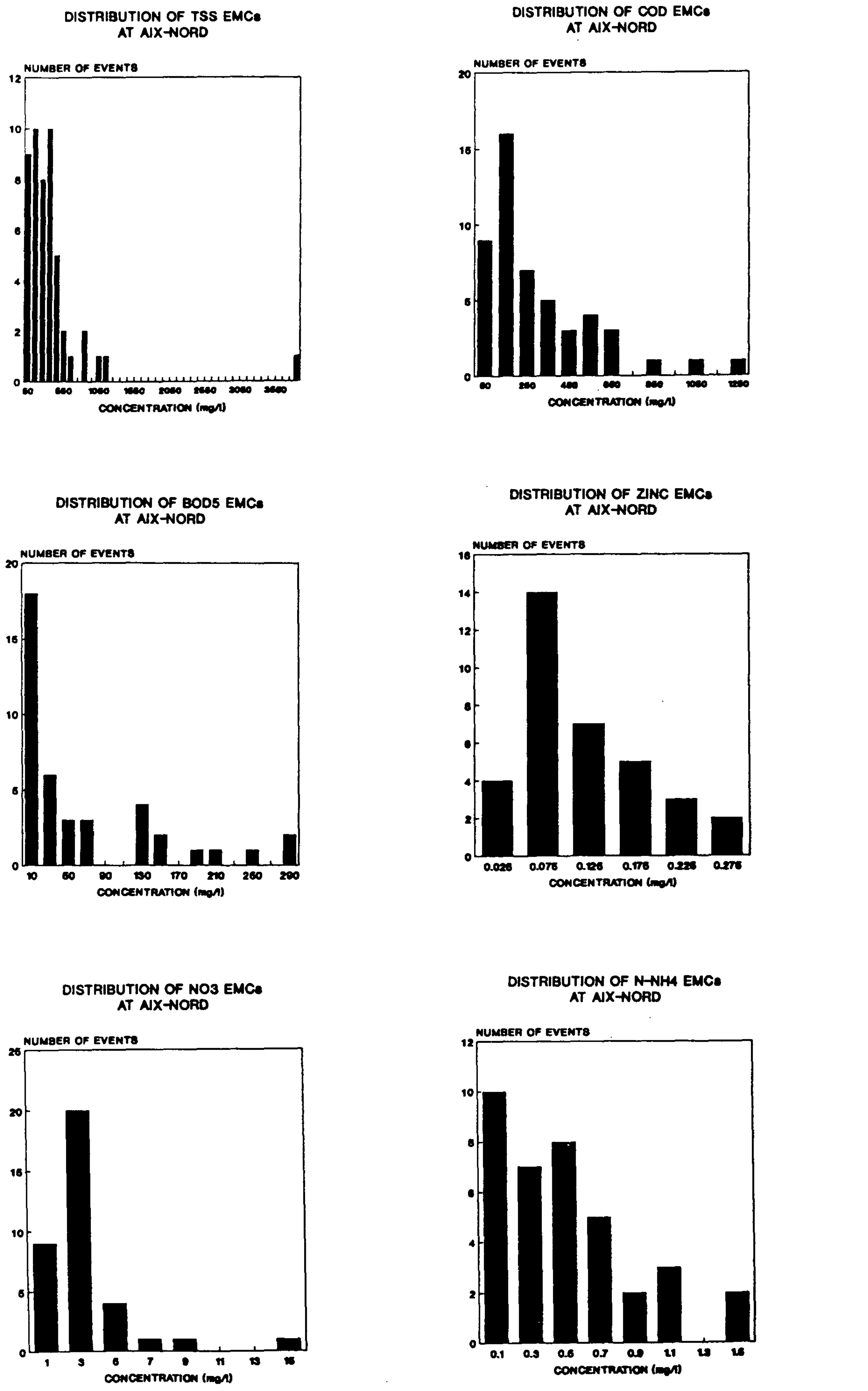


Figure 4.4 EMC histograms of the pollution parameters from the Aix-Nord catchment.

The distribution of TSS could also be affected by hydraulic resuspension effects on in-pipe deposits. Beyond a given velocity of water and critical boundary stress in the pipe, a different population of in-pipe particles could be flushed through, affecting the TSS concentration in the discharge waters. The distributions of other parameters (BOD_5, COD) which are linked to TSS might also be affected.

4.1.2 The Skewness and Coefficient of Variation

Both skewness and coefficient of variation have been computed using formulas that do not take account of any removal of bias . Little further information would be achieved by bias correction. These statistics are presented in Table 4.1 and Table 4.2 whereas the tables displaying the ranked EMCs and their statistics are given in Appendix 4.1. The ranges of the coefficients of variation (CV) are:

* 0.9 to 1.4 for TSS
* 0.8 to 1.3 for COD
* 1 to 1.5 for BOD_5
* 0.5 to 0.9 for Zn
* 0.4 to 0.8 for NO_3^-
* 0.7 to 1.1 for $N\text{-}NH_4^+$

Table 4.1 Coefficients of variation calculated for the event mean concentration of the pollution parameters.

Catchment	Parameters					
	TSS	**COD**	**BOD_5**	**Zn**	**NO_3^-**	**$N\text{-}NH_4^+$**
Maurepas	1.008	0.806	1.040	0.587	0.485	0.9
Les Ulis	0.921	1.276	1.467	0.833	0.435	0.783
Aix-Zup	1.052	0.896	1.391	0.859	0.65	1.108
Aix-Nord	1.428	0.865	1.183	0.522	0.765	0.78

Table 4.2 Skewness calculated for the event mean concentrations of the pollution parameters.

Catchment	TSS	COD	Parameters BOD_5	Zn	NO_3^-	$N\text{-}NH_4^+$
Maurepas	2.313	3.067	4.216	1.436	1.175	1.680
Les Ulis	1.976	3.578	3.817	2.225	2.25	1.6
Aix-Zup	2.747	1.748	3.365	2.078	2.00	2.01
Aix-Nord	4.844	1.726	1.522	0.748	2.611	0.9

For the main pollution parameters (TSS, COD and BOD_5), the ranges of the CV values generally fit into the range quoted in the literature although if a comparison is made with the figures reported by Mancini et. al. (1986) in Table 1.3, the data in Table 4.1 are greater for COD and BOD_5 but are lower than expected for TSS. Some values of CV can be considered to be relatively high in cases of TSS at Aix-Nord (CV = 1.43), COD at Les Ulis (CV = 1.27) and NO_3^- at Aix-Zup (CV = 1.52). The highest COD EMCs having been found at Les Ulis, it is not surprising that this parameter possesses such a high value. Again, this is additional and strong evidence of the possible presence of foul water in the separate drainage water system. Although the highest $N\text{-}NH_4^+$ EMC has been found on the Les Ulis catchment, the CV value is relatively low because the secondary peak of the corresponding histogram (see Figure 4.2) is situated around the mean.

The relatively high value of the CV for TSS at Aix-Nord is due to the very high EMC recorded (3780 mg/l) as shown in Figure 4.4.

The ranges of skewness are:

* 1.9 to 4.9 for TSS
* 1.7 to 3.6 for COD
* 1.5 to 4.2 for BOD_5
* 0.7 to 2.2 for Zn
* 1.2 to 2.6 for NO_3^-
* 0.9 to 1.7 for $N\text{-}NH_4^+$

It is generally rare to find skewness values for EMCs in the literature so it is difficult to know whether the values obtained here are really representative of urban runoff.

The apparently anomalous values for the Aix-Nord catchment are readily noticeable in the data base. The high skewness value for TSS in this catchment is again due to the "exceptional" recorded EMC of 3780 mg/l. The remaining values of skewness are relatively weak in respect of COD, BOD_5, Zinc and $N\text{-}NH_4^+$. Considering the data sets for Aix-Nord were the smallest of the entire data base it is possible that the bias could be responsible for the reduced skewness values but a bias correction shows that the relative discrepancy is not affected. Inspection of the Aix-Nord histograms shows that a short "tailed" distribution can explain the low skewness. This phenomenon could be due to high EMCs not being recorded because of a very low runoff coefficient.

4.2 The Goodness of Fit of the Tested Distributions

4.2.1 Presentation of the Results

The results derived from the computation of the χ^2 and Kolmogorov-Smirnov (KS) tests are presented in four tables (Table 4.3 to 4.6). Each table, corresponding to a given catchment, displays the computed values of the statistical indices for both methods of fitting and for the six pollution parameters corresponding to the data sets presented in Appendix 4.1.

Particular features characteristic of the three parameter distributions fitted by the method of maximum likelihood can be identified:

- in certain cases ($N\text{-}NH_4^+$ at Aix-Nord, Zinc at Aix-Zup, BOD_5 at Les Ulis) the computation of the indices for the three parameter lognormal distribution was not convergent. Nevertheless, the statistical indices were computed using the parameters calculated at the last iteration;

- in the case of the Fréchet (EV2) distribution, the third parameter k cannot be computed for skewness values lower than 1.14. However the accuracy of the "k" computation has been considered to be "poor" when the skewness of the sample is less than 1.4 which is the case for zinc and ammonia at Aix-Nord as well as nitrates at Maurepas. The parameters of the Fréchet distribution could not be calculated for these cases and so the log-Gumbel distribution was applied because the variable $\ln(x)$ follows a Gumbel distribution if x follows a Fréchet distribution. In the following tables an asterisk (*) shows when a log-Gumbel distribution has been applied;

- for many cases the convergence point has not been achieved for the Pearson Type 3 distribution so the parameters of the distribution could not be computed.

- Calculation difficulties and "anomalous behaviour" have been observed for the confidence interval of the three parameter distributions so no notice has been taken of the confidence interval as a tool to estimate the goodness of fit.

Table 4.3 Results of the computation of the χ^2 and Kolmogorov-Smirnov tests for the pollution parameters from the MAUREPAS catchment.

Distribution	Fitting Method	TSS χ^2	TSS KS	COD χ^2	COD KS	BOD_5 χ^2	BOD_5 KS	Zn χ^2	Zn KS	NO_3^- χ^2	NO_3^- KS	$N\text{-}NH_4^+$ χ^2	$N\text{-}NH_4^+$ KS
2 Param. Lognormal	Moments	19,2	0,073	25,4	0,073	60	0,144	11,06	0,0697	9,8	0,0732	25,8	0,137
	Max. Lik.	15.2	0.062	29.8	0.0567	53	0.0621	11.46	0.0686	10.2	0.070	27.4	0.0804
3 Param. Lognormal	Moments	48	0,134	21,4	0,063	60	0,144	19	0,0917	9,77	0,0646	31	0,0875
	Max. Lik.	20.4	0.048	25.06	0.049	53	0.061	8.8	0.042	8.97	0.0728	23.9	0.0687
Gumbel (EV1)	Moments	78,8	0,181	59,8	0,153	102	0,238	24,2	0,107	9,37	0,0682	45,4	0,114
	Max. Lik.	54.8	0.136	3.5	0.077	45.9	0.114	17.8	0.0845	18.17	0.0771	29.8	0.118
Fréchet (EV2)	Moments	57,2	0,14	30,6	0,091	71,8	0,180	16,6	0,0917	28,6*	0,118*	36,6	0,148
	Max. Lik.	16.7	0.0509	23.8	0.061	77.8	0.0645	14.2	0.0763	19.9*	0.785*	38.4	0.124
Gamma	Moments	49,6	0,15	46,6	0,152	97,7	0,253	27,07	0,0948	10,57	0,0543	25,4	0,0722
	Max. Lik.	35.3	0.103	38.4	0.074	48	0.1	20.9	0.101	13	0.0689	26.2	0.0683
Pearson Type 3	Moments	35,6	0,102	207	0,233	202,6	0,215	13,4	0,0820	8,2	0,0579	33,4	0,0769
	Max. Lik.	29.1	0.084	16.2	0.064	48.2	0.094	7.8	0.0707	9.8	0.0630	25.4	0.0621
Sample size			126		126		126		96		87		87

Table 4.4 Results of the computation of the χ^2 and Kolmogorov-Smirnov tests for the pollution parameters from the LES ULIS catchment.

Distribution	Fitting Method	TSS χ^2	TSS KS	COD χ^2	COD KS	BOD_5 χ^2	BOD_5 KS	Zn χ^2	Zn KS	NO_3^- χ^2	NO_3^- KS	$N\text{-}NH_4^+$ χ^2	$N\text{-}NH_4^+$ KS
2 Param. Lognormal	Moments	11,1	0,070	17	0,101	22,6	0,115	16,1	0,0796	5,1	0,106	6,5	0,114
	Max. Lik.	10.18	0.041	10	0.086	15.2	0.123	6.3	0.0790	4.2	0.093	11.4	0.095
3 Param. Lognormal	Moments	26	0,112	39,3	0,189	62,2	0,249	17,3	0,125	7,5	0,1	65	0,111
	Max. Lik.	8.8	0.042	8.4	0.067	13.2	0.097	8.5	0.083	8.7	0.088	7.9	0.132
Gumbel (EV1)	Moments	36,4	0,148	87	0,256	141,8	0,290	26,5	0,176	7,9	0,116	23	0,135
	Max. Lik.	17.1	0.117	34.3	0.180	57.2	0.213	16.8	0.122	2.7	0.084	10.4	0.125
Fréchet (EV2)	Moments	26,4	0,117	57,3	0,205	90,6	0,256	16,9	0,136	5,9	0,084	22,6	0,115
	Max. Lik.	10.9	0.0526	9.6	0.0443	15.2	0.0708	10.9	0.0837	6.2	0.085	13.2	0.104
Gamma	Moments	19,4	0,118	53,8	0,250	69	0,311	20,1	0,160	11,9	0,128	14,2	0,105
	Max. Lik.	14.7	0.092	24.8	0.152	42	0.177	11.5	0.123	7.9	0.108	8.3	0.092
Pearson Type 3	Moments	16,2	0,092	31,8	0,155	28,2	0,205	15,7	0,110	6,7	0,144	11	0,096
	Max. Lik.	15	0.089	-	-	-	-	48.9	0.220	7.9	0.089	26.6	0.153
Sample size			79		79		79		58		47		47

Table 4.5 Results of the computation of the χ^2 and Kolmogorov-Smirnov tests for the pollution parameters from the AIX-ZUP catchment.

Distribution	Fitting	TSS		COD		BOD_5		Zn		NO_3^-		$N\text{-}NH_4^+$	
	Method	χ^2	KS	χ^2	KS	χ^2	KS	χ^2	KS	χ^2	KS	χ^2	KS
	Moments	6	0,087	11,1	0,130	6,8	0,123	11,16	0,162	5,9	0,089	8,9	0,080
2 Param. Lognormal	Max. Lik.	5.6	0.079	3.9	0.092	4	0.093	11.16	0.167	11.5	0.122	5.7	0.080
	Moments	10,7	0,132	17,5	0,131	18	0,181	15,1	0,194	7,1	0,093	18,1	0,156
3 Param. Lognormal	Max. Lik.	5.6	0.076	3.1	0.071	7.6	0.0768	13.6	0.171	6.3	0.094	8.9	0.087
	Moments	3,5	0,196	20,3	0,155	34,8	0,252	28,36	0,238	7,5	0,117	20,5	0,190
Gumbel (EV1)	Max. Lik.	20.7	0.170	18.17	0.173	18	0.155	5.96	0.192	6.3	0.085	15.3	0.126
	Moments	17,9	0,148	9,1	0,109	23,2	0,203	23,9	0,206	6,28	0,943	15,7	0,161
Fréchet (EV2)	Max. Lik.	7.2	0.061	9	0.089	6.4	0.091	3.6	0.147	6.68	0.093	9.7	0.092
	Moments	12,3	0,171	11,5	0,112	10,4	0,182	17,5	0,217	8,7	0,12	8,5	0,103
Gamma	Max. Lik.	10.4	0.136	9.9	0.135	8	0.111	22.7	0.199	7.5	0.098	6.5	0.090
	Moments	10,7	0,132	11,54	0,109	11,2	0,146	15,6	0,208	6,7	0,107	13,7	0,133
Pearson Type 3	Max. Lik.	-	-	-	-	-	-	22.7	0.209	9.1	0.105	35.3	0.218
Sample size			52		52		45		41		48		48

Table 4.6 Results of the computation of the χ^2 and Kolmogorov-Smirnov tests for the pollution parameters from the AIX-NORD catchment.

Distribution	Fitting	TSS		COD		BOD_5		Zn		NO_3^-		$N\text{-}NH_4^+$	
	Method	χ^2	KS	χ^2	KS	χ^2	KS	χ^2	KS	χ^2	KS	χ^2	KS
	Moments	12	0,107	12	0,119	19,3	0,282	4,4	0,112	9,8	0,145	9,2	0,193
2 Param. Lognormal	Max. Lik.	8.4	0.0855	8	0.098	13.2	0.136	2	0.099	9.7	0.156	15	0.154
	Moments	15,2	0,158	16,8	0,145	37,1	0,195	4	0,118	9,86	0,144	3,2	0,0896
3 Param. Lognormal	Max. Lik.	8.4	0.0894	8	0.0896	11.1	0.144	2	0.106	5.46	0.135	4.8	0.133
	Moments	43,6	0,279	18	0,168	36,3	0,206	4,4	0,104	9,3	0,176	2,4	0,098
Gumbel (EV1)	Max. Lik.	13.2	0.122	16.4	0.177	46.9	0.240	4.4	0.100	4.2	0.145	5.2	0.109
	Moments	21,2	0,216	11,6	0,124	4,7	0,126	17,6*	0,150*	10,9	0,130	15,1*	0,215*
Fréchet (EV2)	Max. Lik.	21.2	0.216	7.6	0.0993	12.2	0.116	15*	0.134*	5.46	0.126	27.6*	0.156*
	Moments	26,4	0,256	12,8	0,122	19,6	0,145	2	0,091	10,5	0,155	6,8	0,113
Gamma	Max. Lik.	8	0.113	7.6	0.145	12.8	0.180	4.4	0.092	6.5	0.139	6.4	0.123
	Moments	34,8	0,260	12,8	0,12	46,3	0,196	4	0,114	13,8	0,203	2,4	0,088
Pearson Type 3	Max. Lik.	-	-	-	-	-	-	2.8	0.098	6.5	0.155	4.4	0.115
Sample size			50		50		41		35		36		37

* indicates that the log-Gumbel distribution is applied instead of the Fréchet distribution.

- indicates that no convergence has been reached in the computation of the parameters.

4.2.2 Comparison of the Methods of Moments and Maximum Likelihood Performance

Tables 4.7 to 4.12 collate the relative performance of the statistical tests as defined by both methods of fitting. The tables indicate by which test (χ^2, KS or both) the fit by the method of maximum likelihood is better than the fit by the method of moments. Where "None" is entered in the tables, this indicates that, according to both tests, the method of moments provides a better fit than the method of maximum likelihood.

It must be noted that the Kolmgorov-Smirnov test, applied to the two parameter lognormal distribution (method of maximum likelihood), has been successfully verified by the use of the Statgrafics package.

The overall conclusion that can be drawn from these tables is that the method of maximum likelihood fits the data sets much better than the methods of moments since the percentages of better fit (shown by both indices) in favour of the maximum likelihood estimation vary between 56% and 83% for all the distributions considered. The Fréchet and the three parameter lognormal distributions are the ones presenting the strongest evidence of this fact and the results for the Pearson Type 3 distribution are the most contradictory.

Table 4.7 Reported cases where the χ^2 and KS tests show a better fit for the method of maximum likelihood in comparison with the method of moments for the 2 PARAMETER LOGNORMAL distribution.

Catchment	Pollution Parameters					
	TSS	COD	BOD_5	Zn	NO_3^-	$N-NH_4^+$
MAUREPAS	χ^2-KS	KS	χ^2-KS	KS	KS	KS
LES ULIS	χ^2-KS	χ^2-KS	χ^2	χ^2-KS	χ^2-KS	KS
AIX-ZUP	χ^2-KS	χ^2-KS	χ^2-KS	None	KS	χ^2-KS
AIX-NORD	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2	KS

total number of cases for the KS test = 21/24 = 87%
" " " " " " χ^2 " = 16/24 = 66%
" " " " " both tests = 14/24 = 58%

Table 4.8 Reported cases where the χ^2 and KS tests show a better fit for the method of maximum likelihood in comparison with the method of moments for the 3 PARAMETER LOGNORMAL distribution.

Catchment	Pollution Parameters					
	TSS	COD	BOD_5	Zn	NO_3^-	$N-NH_4^+$
MAUREPAS	χ^2-KS	KS	χ^2-KS	χ^2-KS	χ^2	χ^2-KS
LES ULIS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	KS	χ^2
AIX-ZUP	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2	χ^2-KS
AIX-NORD	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	None

total number of cases for the KS test = 20/24 = 83%
" " " " " " χ^2 " = 21/24 = 87%
" " " " " both tests = 18/24 = 75%

Table 4.9 Reported cases where the χ^2 and KS tests show a better fit for the method of maximum likelihood in comparison with the method of moments for the GUMBEL distribution.

Catchment	TSS	COD	Pollution BOD$_5$	Parameters Zn	NO_3^-	$N\text{-}NH_4^+$
MAUREPAS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	None	χ^2
LES ULIS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS
AIX-ZUP	χ^2-KS	χ^2	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS
AIX-NORD	χ^2-KS	χ^2	None	KS	χ^2-KS	None

total number of cases for the KS test = 18/24 = 75%
" " " " " " χ^2 " = 20/24 = 83%
" " " " " both tests = 17/24 = 71%

Table 4.10 Reported cases where the χ^2 and KS tests show a better fit for the method of maximum likelihood in comparison with the method of moments for the FRECHET distribution.

Catchment	TSS	COD	Pollution BOD$_5$	Parameters Zn	NO_3^-	$N\text{-}NH_4^+$
MAUREPAS	χ^2-KS	χ^2-KS	KS	χ^2-KS	* * χ^2-KS	None
LES ULIS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	None	χ^2-KS
AIX-ZUP	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	KS	χ^2-KS
AIX-NORD	χ^2-KS	χ^2-KS	χ^2-KS	* * χ^2-KS	χ^2-KS	* KS

total number of cases for the KS test = 22/24 = 91%
" " " " " " χ^2 " = 19/24 = 79%
" " " " " both tests = 19/24 = 79%

Table 4.11 Reported cases where the χ^2 and KS tests show a better fit for the method of maximum likelihood in comparison with the method of moments for the GAMMA distribution.

Catchment	TSS	COD	BOD_5	Zn	NO_3^-	$N\text{-}NH_4^+$
	Pollution	Parameters				
MAUREPAS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2	None	KS
LES ULIS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS
AIX-ZUP	χ^2-KS	χ^2	χ^2-KS	KS	χ^2-KS	χ^2-KS
AIX-NORD	χ^2-KS	χ^2	χ^2	None	χ^2-KS	χ^2

total number of cases for the KS test = 17/24 = 71%
" " " " " " χ^2 " = 20/24 = 83%
" " " " " both tests = 15/24 = 62%

Table 4.12 Reported cases where the χ^2 and KS tests show a better fit for the method of maximum likelihood in comparison with the method of moments for the PEARSON TYPE 3 distribution.

Catchment	TSS	COD	BOD_5	Zn	NO_3^-	$N\text{-}NH_4^+$
	Pollution	Parameters				
MAUREPAS	χ^2-KS	χ^2-KS	χ^2-KS	χ^2-KS	None	χ^2-KS
LES ULIS	χ^2-KS	No conv Max Lik	No conv Max Lik	None	KS	None
AIX-ZUP	No conv Max Lik	No conv Max Lik	No conv Max Lik	None	χ^2-KS	None
AIX-NORD	No conv Max Lik	No conv Max Lik	No conv Max Lik	χ^2-KS	χ^2-KS	None

total number of cases for the KS test = 10/16 = 62%
" " " " " " χ^2 " = 9/16 = 56%
" " " " " both tests = 9/16 = 56%

4.3 The Fitting Performance of the Distributions

The goodness of fit performance for the method of maximum likelihood has been assessed for each distribution. To do so a procedure involving weighted scores depending on the level of confidence at which the test is performed has been adopted. The null hypothesis (the population from which the sample is drawn follows the distribution under test) is tested by both χ^2 and Kolmogorov-Smirnov tests at the 5%, 10% and 20% level of confidence:

- if both tests are significant (acceptance of the null hypothesis) at the 20% level of confidence, a total of 8 points is given; only 4 points are given if only one test is significant at the 20% level of confidence;
- if both tests are significant at the 10% level of confidence but not at the 20% level then 4 points are given but 2 points are attributed if only one test is significant at the 10% level of confidence but not at the 20% level;
- if both tests are significant at the 5% level but not at the 10% level then 2 points are given; only 1 point is given if one test is significant at the 5% level but not at the 10% level;
- if a test is not significant at the 5% level of confidence no point is given.

The performance of goodness of fit for each pollution parameter and each distribution is given by the sum of the score from each test. The higher the total score is the better the fit is expected to be. the maximum number of points that the total score can reach in each case is 8 points.

The results of the goodness of fit performance are presented for each distribution in Table 4.13 to Table 4.18. Examination of these tables shows a clear cut-off threshold between the "good" distributions and the "bad" distributions. Indeed, to estimate how good the fit of a particular distribution is on the overall data sets, it would appear that the higher the total score is the better the overall fit is. Three distributions attain similar highest scores:

- the 3 parameter lognormal distribution (total of 160 points);
- the Fréchet (EV2) distribution (total of 157 points);
- the 2 parameter lognormal distribution (total of 156 points).

The other distributions, the gamma distribution (total of 128 points), the Gumbel distribution (total of 99 points) and the Pearson type 3 distribution (total of 82 points but problems of convergence) can no longer be considered as suitable "contestants" to fit the EMC data sets studied in this Report.

It should also be noted that the pollution parameters TSS and COD seem to be the easiest contaminants fitted by the lognormal and Fréchet distributions whereas zinc and nitrates are good secondary pollution parameters to be fitted by the same distributions.

Table 4.13 Goodness of fit performance of the 2 PARAMETER LOGNORMAL distribution (method of maximum likelihood) represented as the sum of scores for both χ^2 and Kolmogorov-Smirnov tests.

	Pollution Parameters					
Catchment	**TSS**	**COD**	**BOD_5**	**Zn**	**NO_3^-**	**$N\text{-}NH_4^+$**
MAUREPAS	8	6	4	8	8	4
LES ULIS	8	8	6	8	8	5
AIX-ZUP	8	8	8	2	5	8
AIX-NORD	8	8	4	8	4	4
TOTAL= 156	32	30	22	26	25	21

Table 4.14 Goodness of fit performance of the 3 PARAMETER LOGNORMAL distribution (method of maximum likelihood) presented as the sum of scores for both χ^2 and Kolmogorov-Smirnov tests.

	Pollution Parameters					
Catchment	**TSS**	**COD**	**BOD_5**	**Zn**	**NO_3^-**	**$N\text{-}NH_4^+$**
MAUREPAS	8	8	4	8	8	4
LES ULIS	8	8	8	8	6	6
AIX-ZUP	6	8	6	2	8	6
AIX-NORD	8	8	4	8	6	6
TOTAL= 160	30	32	22	26	28	22

Table 4.15 Goodness of fit performance of the GUMBEL (EV1) distribution (method of maximum likelihood) represented as the sum of scores for both χ^2 and Kolmogorov-Smirnov tests.

	Pollution Parameters					
Catchment	**TSS**	**COD**	**BOD_5**	**Zn**	**NO_3^-**	**$N\text{-}NH_4^+$**
MAUREPAS	0	4	1	8	6	2
LES ULIS	6	0	0	4	8	6
AIX-ZUP	1	1	4	5	8	4
AIX-NORD	6	1	0	8	8	8
TOTAL= 99	13	6	5	25	30	20

Table 4.16 Goodness of fit performance of the FRECHET (EV2) distribution (method of maximum likelihood) represented as the sum of scores for both χ^2 and Kolmogorov-Smirnov tests.

	Pollution Parameters					
Catchment	**TSS**	**COD**	**BOD_5**	**Zn**	**NO_3^-**	**$N\text{-}NH_4^+$**
MAUREPAS	8	8	4	8	6*	4
LES ULIS	8	8	8	6	8	4
AIX-ZUP	8	8	8	8	8	5
AIX-NORD	6	8	4	4*	6	4*
TOTAL= 157	30	32	24	26	28	17

* shows that the equivalent log-Gumbel distribution is used.

Table 4.17 Goodness of fit performance of the GAMMA distribution (method of maximum likelihood) represented as the sum of scores for both χ^2 and Kolmogorov-Smirnov tests.

	Pollution Parameters					
Catchment	**TSS**	**COD**	**BOD_5**	**Zn**	**NO_3^-**	**$N\text{-}NH_4^+$**
MAUREPAS	4	4	4	6	8	4
LES ULIS	8	1	0	6	8	8
AIX-ZUP	6	6	8	1	8	8
AIX-NORD	8	8	2	8	6	6
TOTAL= 128	26	19	6	21	30	26

Table 4.18 Goodness of fit performance of the PEARSON TYPE 3 distribution (method of maximum likelihood) presented as the sum of scores for both χ^2 and Kolmogorov-Smirnov tests.

	Pollution Parameters					
Catchment	**TSS**	**COD**	**BOD_5**	**Zn**	**NO_3^-**	**$N\text{-}NH_4^+$**
MAUREPAS	6	8	4	8	8	4
LES ULIS	6	No Conv.	No Conv.	0	6	4
AIX-ZUP	No Conv.	No Conv.	No Conv.	1	6	0
AIX-NORD	No Conv.	No Conv.	No Conv.	8	5	8
TOTAL= 82	12	8	4	17	25	16

4.4 Graphical Fitting Examples

Some graphical fitting examples are presented in this section as an illustration of the goodness of fit findings.

Figures 4.5 to 4.7 show good examples of the two parameter lognormal distribution fitting of three pollution parameters from the Aix-Nord and Aix-Zup catchments. Figures 4.8 to 4.10 show examples of the 3 parameter lognormal fit upon TSS and zinc EMCs from the Les Ulis and Maurepas catchments. Figures 4.9 and 4.10 give a comparison of the two fitting procedures used in this study (moments and maximum likelihood) for the same data set. This comparison illustrates the fact widely observed throughout this study that the method of moments is influenced by the high values of the data set. This is the reason why the upper part of a moments fitted line usually presents a better fit than a line fitted by the method of maximum likelihood. The latter gives less weight to the high values of the data set. The overall goodness of fit obtained from the method of maximum likelihood tends however to be better than the one resulting from the method of moments.

Figures 4.11 to 4.12 show examples of good fit for the Fréchet (EV2) distribution.

Figure 4.13 shows a typical fit observed throughout this study for the Gumbel distribution: a concave bow shape of the plotting positions with a fitted line underestimating the values in the tails. This "behaviour" of the Gumbel distribution suggested that a better fit would be obtained if the Fréchet distribution was applied (see Fig. 3.12 in chapter 3).

Figure 4.14 displays a relatively good fit of the gamma distribution with the method of moments although a slight concave bow shape can be noticed which has often been noticed for the gamma distribution.

2 PARAMETER LOGNORMAL DISTRIBUTION FITTED ON N-NH4 EMCs FROM AIX-ZUP

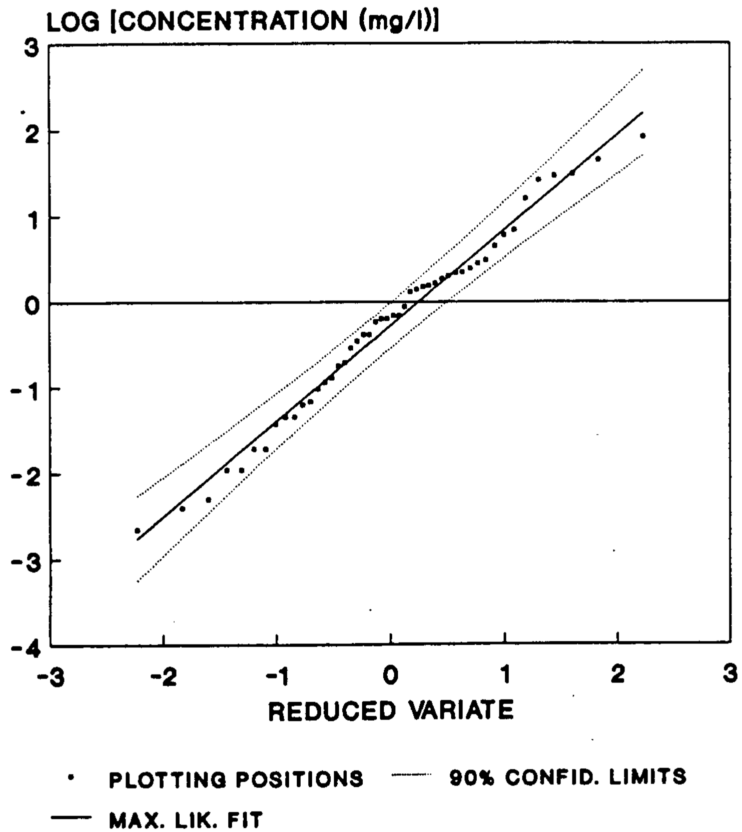


Figure 4.5 Example of a 2 parameter lognormal distribution fitted by the method of maximum likelihood on N-NH_4^+ EMCs from Aix-Zup.

2 PARAMETER LOGNORMAL DISTRIBUTION FITTED ON COD EMCs FROM AIX-NORD

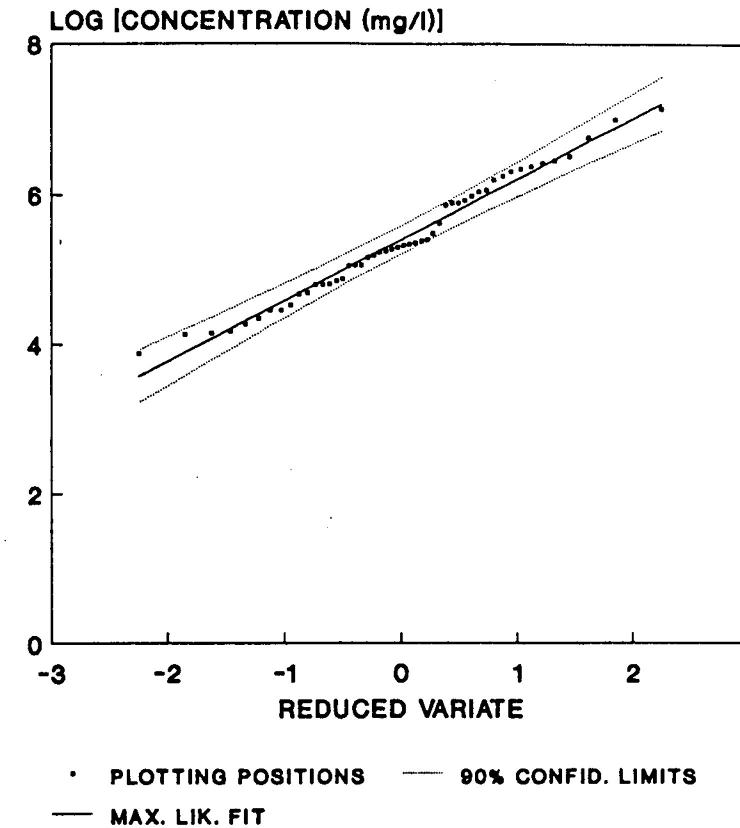


Figure 4.6 Example of a 2 parameter lognormal distribution fitted by the method of maximum likelihood on COD EMCs from Aix-Nord.

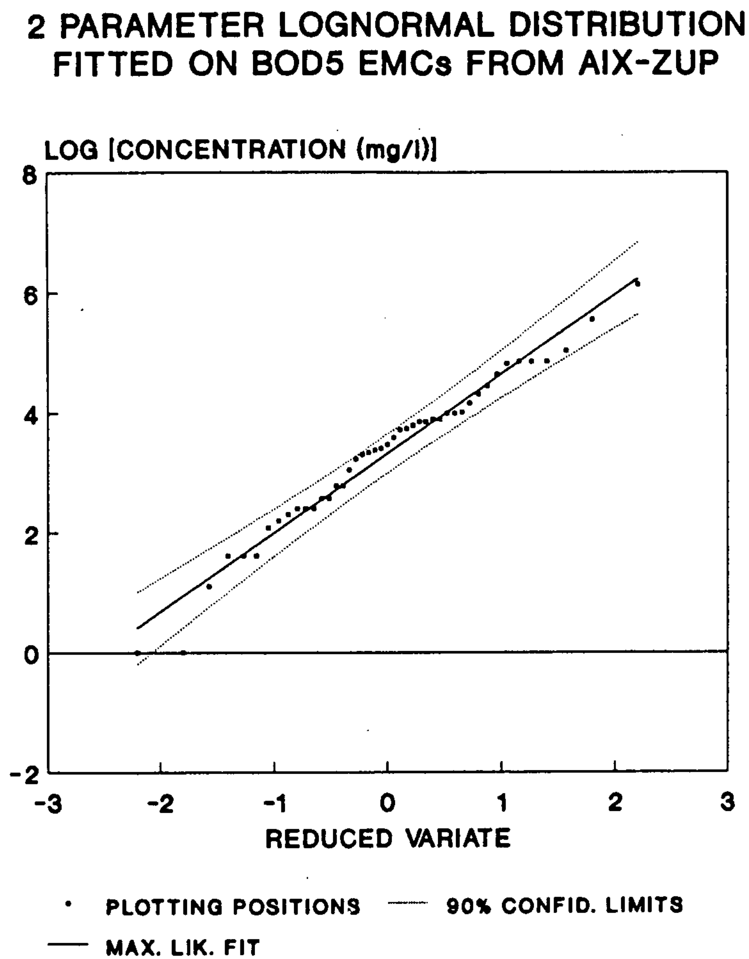


Figure 4.7 Example of a 2 parameter lognormal distribution fitted by the method of maximum likelihood on BOD_5 EMCs from Aix-Zup.

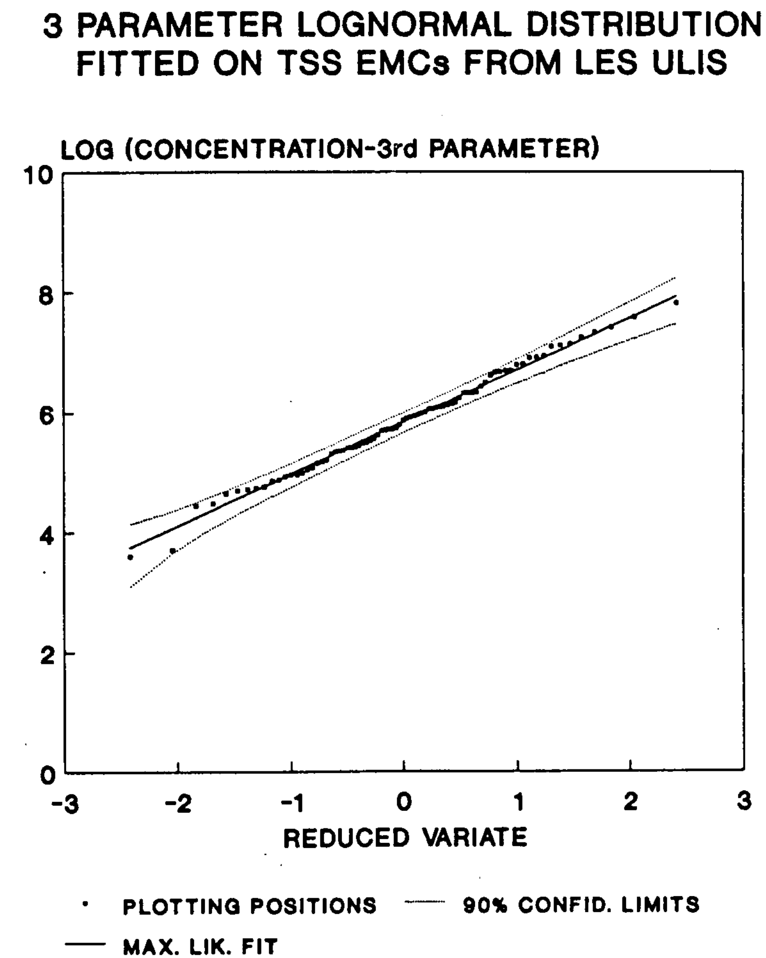
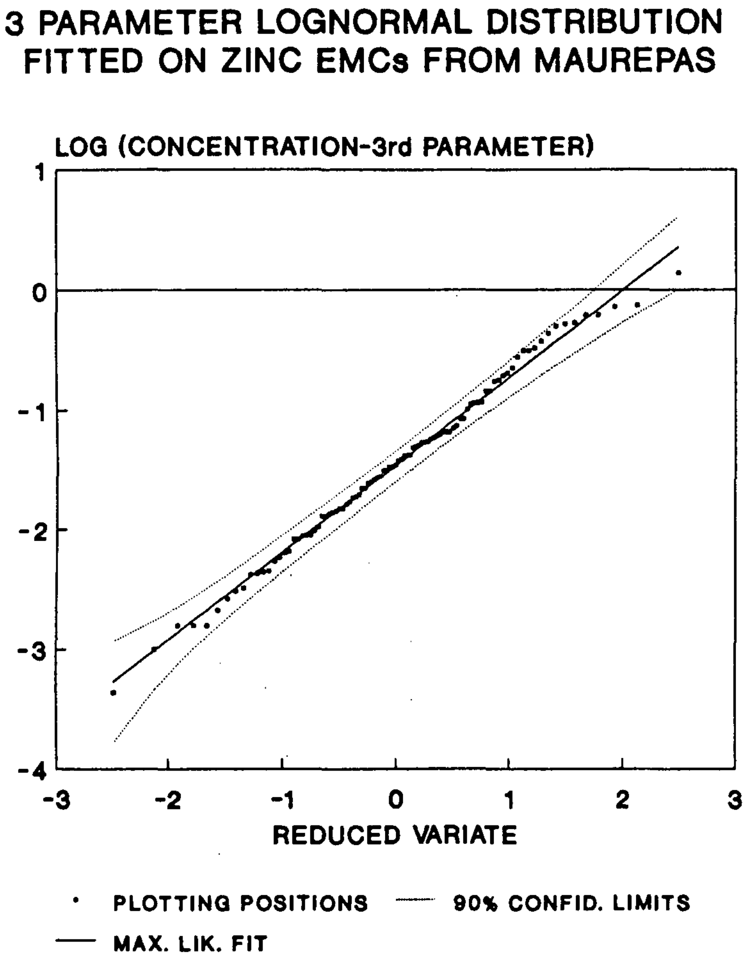


Figure 4.8 Example of a 3 parameter lognormal distribution fitted by the method of maximum likelihood on TSS EMCs from Les Ulis.



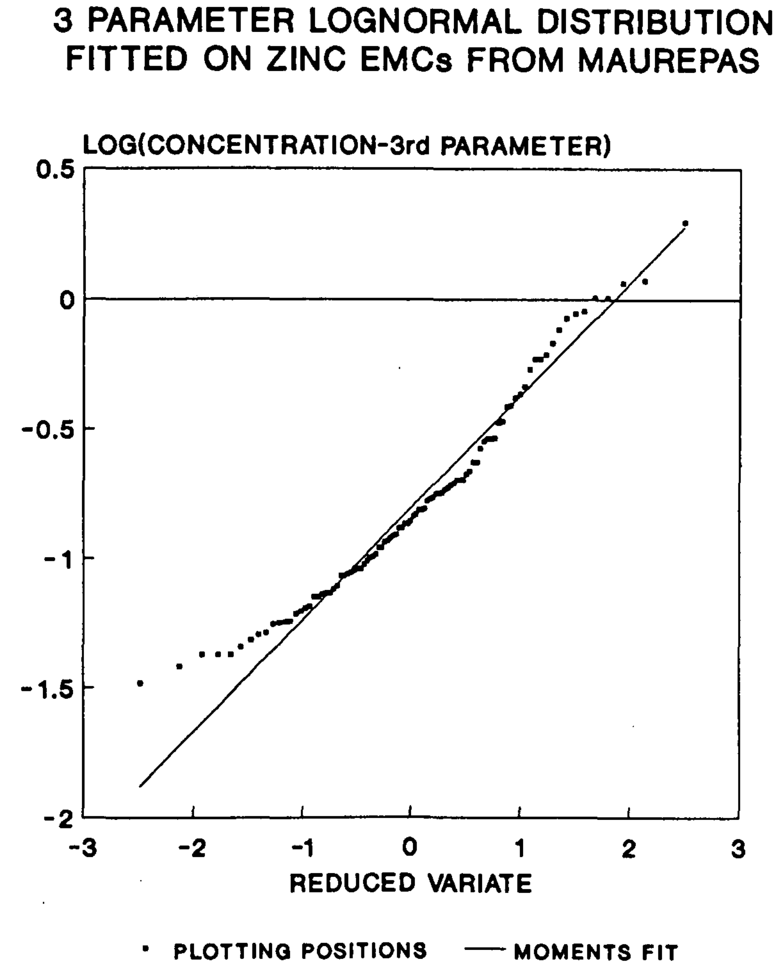


Figure 4.9 Example of a 3 parameter lognormal distribution fitted by the method of maximum likelihood on Zinc EMCs from Maurepas.

Figure 4.10 Example of a 3 parameter lognormal distribution fitted by the method of moments on Zinc EMCs from Maurepas.

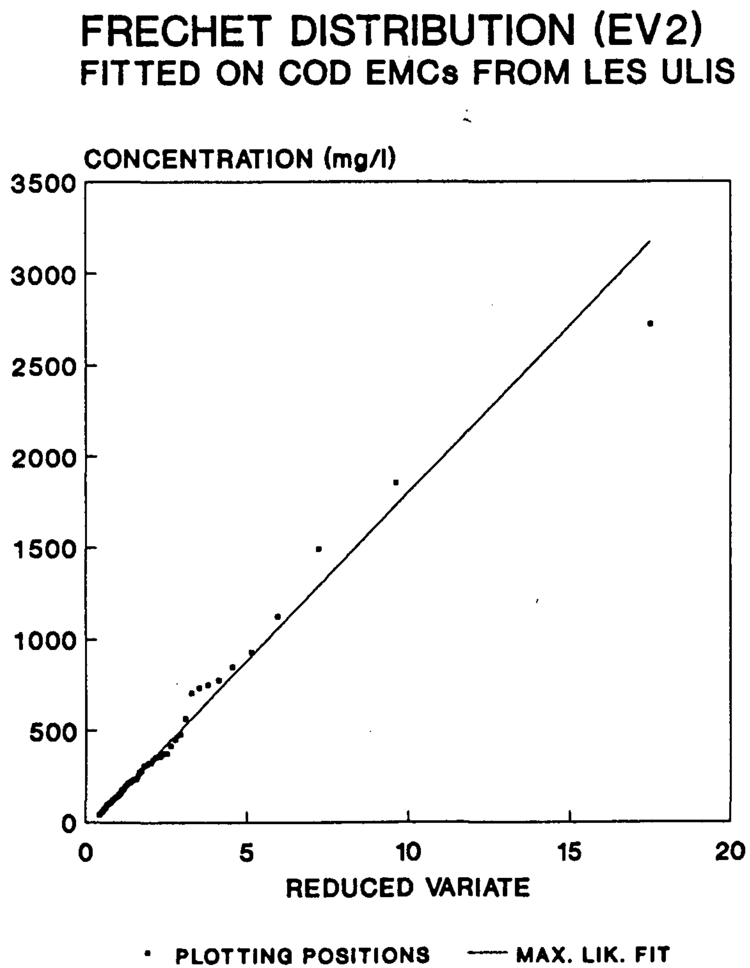


Figure 4.11 Example of a Fréchet distribution (EV2) fitted by the method of maximum likelihood on COD EMCs from Les Ulis.

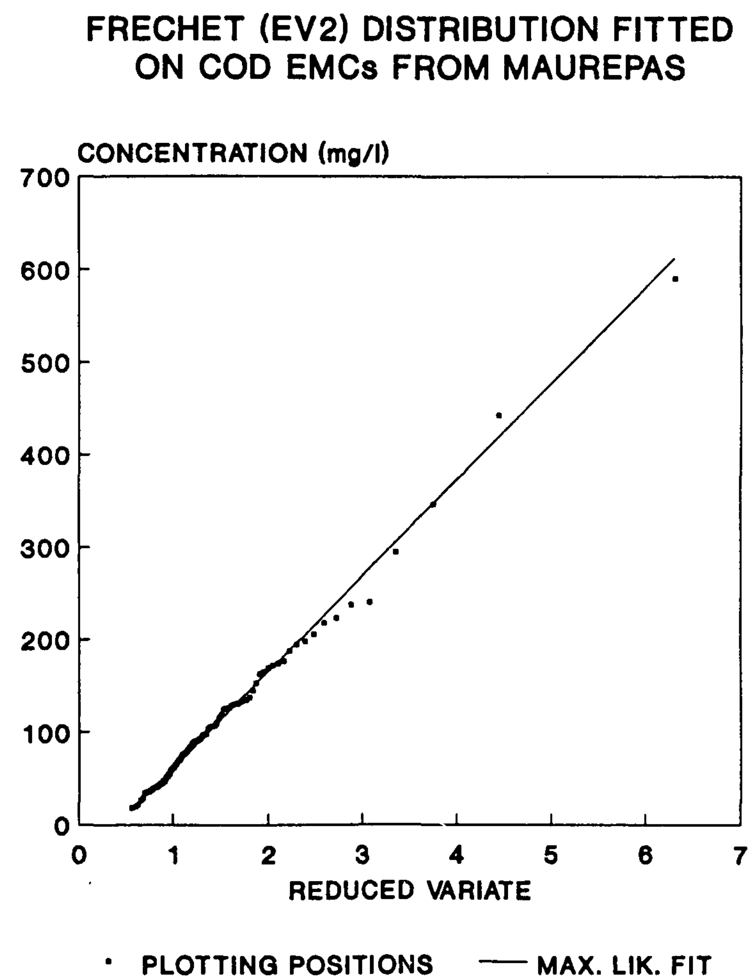


Figure 4.12 Example of a Fréchet distribution (EV2) fitted by the method of maximum likelihood on COD EMCs from Maurepas.

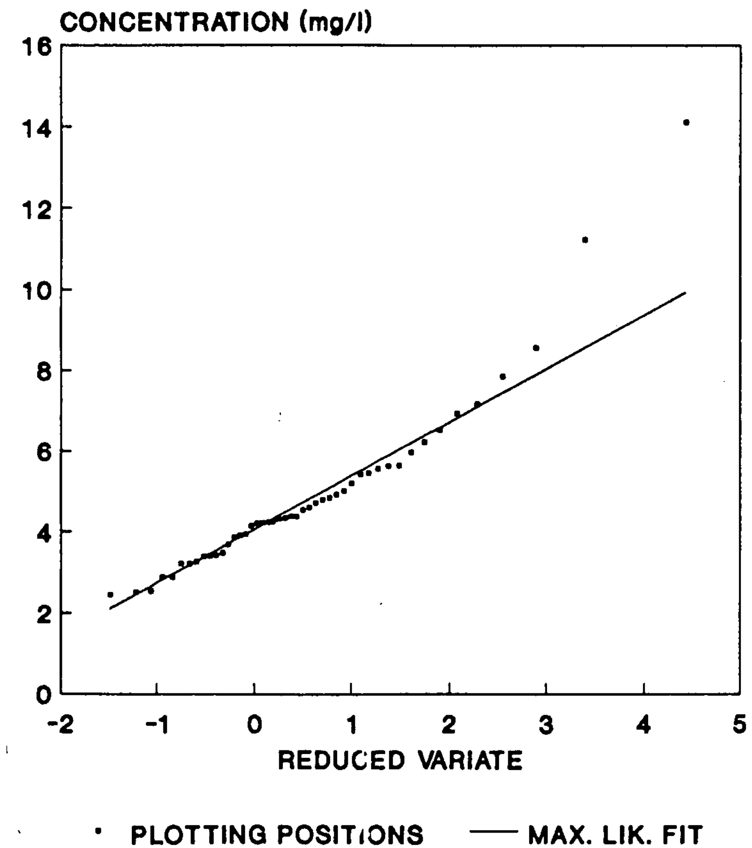


Figure 4.13 Example of a Gumbel distribution fitted by the method of maximum likelihood on NO_3^- EMCs from Les Ulis.

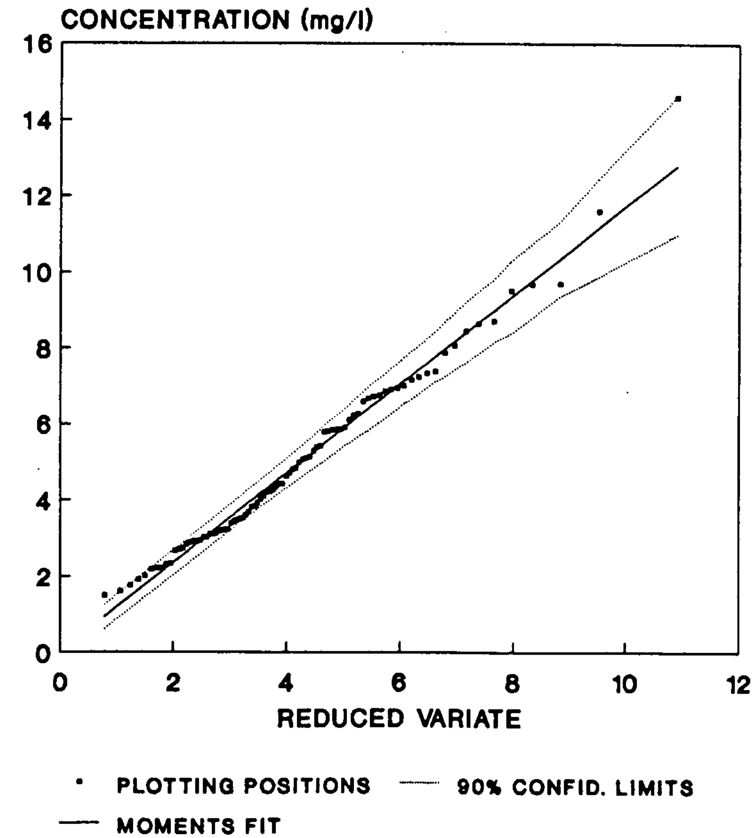


Figure 4.14 Example of a gamma distribution fitted by the method of maximum likelihood on NO_3^- EMCs from Maurepas.

4.5 Conclusion

The outcome of the overall comparison undertaken for the best suited distributions and fitting procedures can be summarised as follows:

- the method of maximum likelihood gives better results than the method of moments although the rarer high EMCs can be better fitted by the method of moments.

- the three best suited distributions seem to be the three parameter lognormal distribution, the Fréchet (EV2) distribution and the two parameter lognormal distribution. The literature review presented in Chapter 1 shows that the two parameter lognormal distribution has previously been found suitable for EMC data. Surprisingly the Fréchet distribution, usually used as an extreme values distribution, has also been found suitable despite a theoretical background derived from extreme values statistics.

- TSS and COD EMCs seem to be more easily fitted by the three more suitable distributions than any other pollution parameters.

CHAPTER 5: THE STEPWISE REGRESSION ANALYSIS

5.1 Introduction and Background

A stepwise regression analysis has been undertaken to ascertain the degree to which hydrological or climatic parameters could explain the variations of several pollutant EMCs and to determine if a regionalisation is possible between the data for the northern and the southern catchments.

This work is complementary to the previous distributional analysis and will provide a better understanding of the modelisation of EMC variation.

The main findings of a multiple regression analysis carried out in the same spirit by the Ministère de l'Urbanisme, du Logement et des Transports (1985), are presented in Section 2.5 of this Report for the main pollution parameters and in Section 2.6.1 for the secondary pollution parameters. Although these findings are interesting, they are not detailed enough so a more detailed presentation is given in the present Section.

The results of a stepwise regression analysis for TSS EMCs is presented in Desbordes et. al. (1984) for the four French catchments. The general outcome of this previous study was that, amongst the explanatory variables, the mean maximum intensity during a 5 minutes time interval (IMAX5) and the duration of the dry weather period preceeding the event (DTS) are the most important variables. However the main explanatory variable for the TSS EMCs is IMAX5 for the southern catchments whereas DTS presents the highest correlation with TSS EMCs for both northern catchments. The hypothesis proposed to explain this regionalisation were that "in the south of France (Aix-en-Provence), dry weather periods are much longer (almost twice) than in the north, on an average basis. So dusts should be more consolidated and their removal should necessitate higher rainfall intensities" and "in the north of France (Maurepas and Les Ulis), dry weather periods are shorter, so dusts should be less consolidated, and the catchments are washed off by rainfall more frequently. The dry weather period duration DTS seems to be the best explanatory variable in that case".

As a complementary study to this approach, a similar stepwise regression analysis has been undertaken for several pollution parameters such as TSS, BOD_5, COD, zinc, ammonia and total phosphorus.

5.2 Results of the Stepwise Regression Analysis

The stepwise regression analysis was performed with the STATGRAFICS package on an IBM PC compatible microcomputer. The confidence threshold for hypothesis testing of a zero correlation coefficient was 5% and the procedure used was a backwards selection.

The pollution parameters tested are:

TSS: EMCs of total suspended solids (mg/l);
COD: EMCs of chemical oxygen demand (mg/l);
BOD: EMCs of 5 days biological oxygen demand (mg/l);
Zn : EMCs of zinc (mg/l);
TOTP: EMCs of total phosphorus (mg/l);
NNH4: EMCs of N-ammonia (mg/l).

The tested explanatory variables are:

QMAX: peak discharge of the event (l/s);
ITC: mean maximum intensity during the time of concentration (mm/h);
IMAX5: mean maximum intensity during a 5 min interval (mm/h);
VR: runoff volume during the event (m^3);
R: amount of rainfall during the event (mm);
DTS: antecedent dry period duration before the event (days).

The results of the stepwise regression analysis are summarised in Table 5.1. The explanatory variables are presented by order of importance in the stepwise relationships.

The correlation coefficients obtained are not as high as the ones computed for the event mean loads as reported by Hémain (1983) for a similar stepwise regression analysis. Event mean loads seem more strongly correlated with climatic and hydrological explanatory variables (especially with QMAX) than EMCs do.

However before analysing the results presented in Table 5.1 it must be emphasised that three explanatory variables are strongly correlated for all the catchments as displayed in Table 5.2: QMAX, ITC and IMAX5. The correlations between R and IMAX5 can also be significant (except at Les Ulis): 0.41 at Aix-Nord, 0.57 at Aix-Zup and 0.61 at Maurepas.

Table 5.1 Results of the stepwise regression analysis.

Catchment		Stepwise relationship	Multiple correlation coefficients	Number of observations
AIX-NORD	TSS	= 14,43 IMAX5 - 6,19 R + 213,13	0,764	46
	TSS	= 6,35 IMAX5 - 9,48 R + 306,66	0,378	46
	BOD	= -0,19 QMAX + 6,50 IMAX5 + 50,73	0,408	37
	ZN		not sign.	32
	TOTP	=0,0007 QMAX -0,0002 VR + 1,0	0,543	22
	NNH4	= 0,036 DTS + 0,39	0,439	35
AIX-ZUP	TSS	= 0,41 QMAX - 11,12 R + 293,01	0,469	48
	COD	= 5,69 IMAX5 - 11,39 R + 290,60	0,385	48
	BOD		not sign.	
	ZN		not sign.	
	TOTP		not sign.	
	NNH4	=-0,097 ITC + 1,76	0,296	45
LES ULIS	TSS	= 68,14 DTS - 31,41 R + 15,57 IMAX5 + 301	0,800	64
	COD	= 73,10 DTS - 26,23 R + 231,1	0,822	64
	BOD	= 17,68 DTS - 4,11 R - 9,79 IMAX5 + 67,2	0,815	64
	Zn	= 0,039 DTS - 0,023 R + 0,009 IMAX5 + 0,36	0,618	51
	TOTP	= 0,39 DTS - 0,095 R + 1,79	0,778	41
	NNH4	= 0,305 DTS + 1,14	0,691	41
MAUREPAS	TSS	= 17,83 DTS + 8,08 IMAX5 - 8,16 R + 104,4	0,716	96
	COD	= 12,30 DTS - 3,08 R + 82,8	0,677	96
	BOD	= 2,7 DTS - 0,79 R + 14,4	0,710	96
	Zn	= 0,015 DTS +0,005 IMAX5 + 0,28	0,464	79
	TOTP	= 0,13 DTS -0,044 R + 0,018 IMAX5 + 0,88	0,721	68
	NNH4	=-0,073 R + 0,0003 VR + 1,34	0,221	74

Table 5.2 Simple correlations coefficients between some of the explanatory variables. After Desbordes et. al. (1984).

Relationships	AIX ZUP	AIX NORD	LES ULIS	MAUREPAS
QMAX ; ITC	0.975	0.957	0.907	0.961
QMAX ; IMAX5	0.964	0.948	0.825	0.869
ITC ; IMAX5	0.989	0.913	0.857	0.910

The results of the stepwise regression analysis show that correlations are more significant for the northern catchments than for the southern catchments for reasons which are rather difficult to appreciate.

The predominant explanatory variables are IMAX5 and QMAX (which are strongly correlated) for the southern catchments whereas DTS is undoubtedly the main variable for the northern catchments. Although this differentiation would seemingly go in favour of a regionalisation hypothesis as explained in Section 5.1, local catchment characteristics might have an important role to play. Indeed the catchment average slopes are greater for both southern catchments (6.5% at Aix-Nord and 2.9% at Aix-Zup) than for the northern catchments (0.5%). This fact suggests that steep slopes give more weight to high rainfall intensities in the process of generating runoff pollutant concentrations.

The variables VR and ITC do not seem to play a major role as explanatory variables. The variable R is always present in the stepwise relationships as the secondary variable explaining TSS and COD EMC variations.

TSS is the pollution parameter which usually presents the strongest correlation of the three main pollution parameters whereas total phosphorus presents the highest correlation of the three minor pollution parameters. The overall smallest correlations are obtained for zinc and ammonia whose variations must strongly depend on non-climatic and non-hydrological factors.

5.3 Conclusion

The conclusion we can draw from this study is that not knowing to what extent the regionalisation hypothesis may be valid, it is not possible to apply a general model describing the EMC variation and thus we reach the same conclusion as Jewell et. al. (1982) "that local data should be gathered for each basin to be modelled and a representative model derived using statistical techniques". However in the case of this study the multiple correlation coefficients derived for the main parameters (TSS, COD and BOD_5) are not particularly high: varying from 0.38 to 0.82. The main explanatory variables are the 5 min maximum rainfall intensity and the peak flow for the southern catchments and the dry weather duration for the northern catchments. The amount of rainfall is an overall good secondary variable for the four French catchments.

CHAPTER 6: SUMMARY AND RECOMMENDATIONS

The outcome of this Report can be summarised by the following comments:

- the statistical analysis shows that an overall better fit is obtained upon EMCs distributions by applying the method of maximum likelihood rather than the method of moments (independently of the distribution tested);

- three distributions show similar fitting performances (by the method of maximum likelihood) over the EMC data sets tested:
  * the three parameter lognormal distribution;
  * the Fréchet (EV2) distribution;
  * the two parameter lognormal distribution.

  The latter method is regarded as being the most convenient to handle whereas the two other distributions have never been tested before.
  The data sets which show a better fit with the three distributions cited, seem to be TSS EMCs and COD EMCs;

- the stepwise regression analysis, applied to EMCs clearly shows a differentiation between the southern and northern catchments probably because of a combination of climatic conditions and catchment characteristics. Although the multiple correlation coefficients are relatively small (varying from 0.38 to 0.82 for BOD_5, TSS and COD), the peak flow and the maximum rainfall intensity over a five minutes time interval seem to be the main explanotory variables (amongst the ones tested) for the southern catchments. The antecedent dry period, on the other hand, is the most important variable to explain the EMC variation for the northern catchments.

This study, through its consistent approach to quantify the goodness of fit of several distributions (using the computation of statistical tests), has added to the knowledge of stormwater quality variability and might form the basis for further application in more integrated approaches involving mass balance.

More research is needed with bigger EMC sample sets to assess the robustness of the distributions selected and to eventually choose the most reliable and reproducible to be used in any EMC simulation study or engineering control and impact assessment work.

The same approach ought to be applied to pollutant loadings on an event basis (i.e short-term effects) or a yearly basis (i.e long-term effects) in order to increase the knowledge of load variability which is the product of single discharge variability and EMC variability.

The application of the same methodology to CSO EMCs and loadings, as well as treatment plant discharges, might reveal similar or different patterns that could help to provide a theoretical basis for the outcome of distributional analyses.

At the end of this study a few points must be emphasised:

- further statistical work should be undertaken to assess the importance of "mixed distributions" present in the underlying EMC population;

- the effect of "peak over a threshold" features (linked to hydrological parameters such as peak flow or amount of rainfall), must be considered in the collection of EMC samples since small runoff flows are insufficient to trigger the sampling machine and, if a sampling does occur, the amount of water collected might be too small to allow all the chemical analyses to be performed thus reducing the size of the EMC data set;

- in terms of the distribution that should be used to model the pollutant variability, a convenience factor might be considered and not just the best fitting performance. This might involve a review of convergence problems or assessing to what extent the linear combination of EV variables, for example, can be considered as a linear variable.

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APPENDIX 1.1

Extract of EEC water quality standards. Council directive of 16 June 1975 concerning the quality required of surface water intended for the abstraction of drinking water in the Member States and council directive of 18 July 1978 on the quality of fresh waters.

	Surface water intended for the abstraction of drinking water						Freshwaters supporting fish life		
Parameters	A1		A2		A3		Salmonid waters		Minimum sampling & measuring frequency
	G	I	G	I	G	I	G	I	
TSS mg/l SS	25						⩽25(O)		
Nitrates mg/l NO_3	* 25	50(O)	*	50(O)	*	50(O)			
Zinc mg/l Zn	0.5	3	1	5	1	5		⩽0.3	monthly
Dissolved oxygen saturation rate % O_2 or as indicated	* >70		* >50		* >30		50%⩾9 mg/l		monthly, minimum 1 sample representative of low O_2 conditions of the day of sampling. However, where major daily variations are suspected a minimum of 2 samples in 1 day shall be taken.
COD mg/l O_2	*		*		* 30				
BOD_5 mg/l O_2	* <3		* <5		* <7		⩽3		
Ammonia mg/l NH_4	0.05		1	1.5	2	4(O)	⩽0.04	⩽1(O)	monthly

I = mandatory (>95% of the samples taken at regular intervals must comply with the parametric value).
G = guide (>95% of the samples taken at regular intervals must comply with the parametric value).
O = derogation in exceptional climatic or geographic conditions.
* = this directive may be varied in special conditions: floods or natural disasters, natural enrichment, stagnant water...

APPENDIX 2.1. Detailed characteristics of the experimental French catchments. After the Laboratoire d'Hydrologie Mathématique (1986).

catchment characteristics	AIX-NORD	AIX-ZUP	LES ULIS	MAUREPAS
Total area (ha)	92.0	25.0	43.1	26.7
Area of roofing connected to the drainage system (ha)	22.6	9.47	-	4.3
Area of: roads	-	4.89	-	9.55
pavement	17.22	4.28		1.38
Impervious average (%) (INT 77/287)	52	77	42	60
Total imperviousness connected to the drainage system	60	74	42	60
Average slope of the network (m/m)	0.08	0.029	0.0055	0.0050
Individual housing area (ha)	6.45	0.92	-	18.8
Collective housing area (ha)	11.84	6.72	-	4.47
Trading activity area (ha)	4.3	0.36	-	-
Lawn area (ha)	50.57	7.03	-	-
Car park area (ha)	5.38	3.66	-	-
Coating: road & pavement	concrete tar	concrete tar	tar	concrete tar
roofing	tiles, flat roof	flat roof	flat roof (tower blocks)	tiles, flat roof
Total length of roads (m)	5500	6800	-	6625
Cleaning of: streets	-	sweeping	sweeping	sweeping (1/wk)
gutters	sweeping	-	sweeping	sweeping
Domestic refuse collection	6/wk	6/wk	3/wk	3/wk
Water level during dry weather (cm)	3	3	5 (6 l/s)	2.5 (4 l/s)
Nature of dry weather flow	springs	irregular washing	-	agricultural drainage
Point of measure:				
slope (m/m)	0.0013	0.0017	0.0004	0.0083
length of straight section (m)	40	40	69	150
Calibration method for flow measurement	Manning Strickler	Bazin-, Mann,Str,	-	-
Network (last visited)	visitable (1979)	visitable (1979)	visitable	visitable
Water tightness	good	good	-	-
Coating	smooth concrete	smooth concrete	vibrated concrete	vibrated concrete

APPENDIX 2.2 Main characteristics of observed events. After Hémain (note 25/1983, 1983).

Keys:

NUM: chronological number of event. Values >1000 correspond to multiple mean samples. The first number is the number of events involved whereas the last three numbers are the number of the first event.

DATE: date of event occurrence (year and Julian date).

CD: quality code of discharge data:
0: missing value
1: correct value
2: suspicious value
5: incomplete hydrograph.

VR: runoff volume (m^3).

QMAX: peak flow (l/s).

CP: quality code of rainfall data:
0 to 2: eg. CD
3: data from another site than the one set up in the catchment
8: cumulative rainfall recorded
9: measurement with the bucket
*: rainfall corresponding to several runoff events.

HP: amount of rainfall (mm).

DP: rain duration (1/1000 day).

IM/14,21 or 31: average maximum intensity during the time of concentration (mm/h).

IM4: average maximum intensity (mm/h) during 4/1000 day (about 5 minutes).

DTS: antecedent dry period duration (days).

DCO, MES, DBO5, Zn, NO3, N-NH4: event mean concentrations of COD, TSS, BOD_5, Zn, NO_3^- and $N\text{-}NH_4^+$ (mg/l) drawn from:
M: average sample
F: average sample reconstituted with the bottles
P: pollutogramme.

Catchment: MAUREPAS

NUM	DATE	CD	VR m3	QMAX l/s	CP	HP mm	DP mJ	IM 21 mm/h	IM 4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
1	80248	1	252	130	1	2.4	66	3.4	6.3		F 95	F 127	F 24	0.890		
2	80255	1	324	185	1	3.2	51	5.8	18.2	7.3						
3	80263	1	1511	1380	1	10.4	45	19.3	60.4	8.0	P 163	P 635	P 21	0.470	3.100	1.090
4	80265	1	399	140	1	3.0	41	4.1	7.3	1.45	F 87	F 182	F 14	0.250	4.600	0.620
2003	80263	1	1910	1380	1	13.4	86	19.3	60.4	8.0	M 161	M 337	M 22			
5	80267	1	67	50	1	1.6	25	2.8	4.9	1.95	F 61	F 126	F 19			
6	80267	1	65	50	1	1.0	62	1.4	3.1	.35	F 87	F 153	F 24			
7	80268	1	178	85	1	1.8	121	1.9	3.6	.45	F 59	F 96	F 13			
2006	80267	1	243	85	1	2.8	183	1.9	3.6	.35	M 76	M 114	M 20			
8	80280	1	1050	390	1	7.4	64	7.5	25.0	12.0	P 144	P 223	P 36	0.470	3.500	0.690
9	80280	1	193	125	1	1.6	3			.25	F 90	F 164	F 23			
10	80281	1	103	90	1	1.4	33	2.6	12.6	.95						
11	80281	1	230	115	1	1.4	60	2.1	6.3	.1	F 73	F 97	F 15	0.270		
12	80282	1	382	85	1	2.0	79	1.3	1.7	.35	F 21	F 34	F 8	0.190	6.100	0.490
13	80283	1	2276	350	1	11.3	210	6.0	7.1	1.4	P 55	P 89	P 9	0.240	2.900	2.660
14	80283	1	926	320	1	6.4	287	5.9	6.5	.1	P 40	P 34	P 5	0.140	2.300	2.640
15	80284	1	384	55	+1	6.4	287	5.9	6.5	.1	F 40	F 25	F 7	0.140	6.900	2.410
16	80284	1	93	50	1	1.0	95	.9	1.4	.7						
17	80285	1	914	125	1	4.4	152	1.8	3.0	.2	P 34	P 24	F 6	0.330	9.700	1.720
5013	80283	1	4593	350	1	23.6	744	6.0	7.1	1.4	M 43	[illegible] 53	M 13			
18	80289	1	182	70	1	4.4	344	1.5	4.2	3.95	F 69	F 110	F 18	0.300		
19	80289	1	604	160	+1	5.8	338	2.4	3.3	.15	F 28	F 43	F 5	0.350	4.200	1.080
20	80290	1	159	85	+1	5.8	338	2.4	3.3	.15						
21	80291	1	32	35	1	.6	9		2.8	1.0						
22	80291	1	103	70	1	.6	63	.6	2.2	.5						
23	80295	0			1	2.6	157	3.5	9.4	4.2						
24	80296	1	625	315	1	3.4	61	4.5	10.1	.6	F 85	F 415	F 12	0.420	2.000	1.080
25	80297	1	595	70	1	3.2	180	1.7	3.3	.35						
26	80297	1	347	295	1	1.6	4		16.7	.25	F 164	F 502	F 15	0.730	1.600	2.350

Catchment: MAUREPAS

NUM	DATE	CD	VP m3	QMAX l/s	CP	HP mm	DP mn	IM/21 mm/h	IM/4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
27	80318	1	78	60	*1	18.6	656	3.1	4.9	21.35						
28	80318	1	1288	220	1	18.6	656	3.1	4.9	21.35	P 61	P 71	P 10	0.570	2.200	0.570
29	80319	1	1801	195	1	18.6	656	3.1	4.9	21.35	P 36	P 41	P 6	0.290	3.200	0.250
30	80319	1	399	235	*1	18.6	656	3.1	4.9	21.35	F 137	F 258	F 16	0.580	2.900	0.300
31	80319	1	144	90	1	2.0	202	1.3	2.5	.15						
32	80320	1	620	100	*8	8.6				.1						
33	80320	1	1536	230	*8	8.6				.1	F 61	F 34	F 5	0.240	3.000	0.030
7027	80318	1	5861	235	8	29.2				21.35	M 44	M 60	M 6			
34	80328	5	1600	165	1	9.8	541	3.0	4.2	7.95	M 197	M 183	M 109	0.420	1.900	0.190
35	80330	1	245	90	1	2.0	265	1.2	2.3	.5						
36	80332	1	100	45	1	1.6	226	.9	2.2	1.5	F 97	F 215	F 12			
37	80332	1	112	50	*1	2.2	170	1.4	1.9	.1	F 133	F 314	F 16			
38	80332	1	279	95	*1	2.2	170	1.4	1.9	.1	F 89	F 186	F 12	0.890	5.800	1.530
39	80336	1	736	40	1	3.8	356	1.3	2.4	3.85	F 195	F 92	F 17	0.550	5.900	3.220
40	80337	1	229	55	1	.8	12		4.2	.55	F 83	F 129	F 22			
2039	80336	1	965	55	1	4.6	368		4.2	3.85	M 61	M 79	M 10			
41	80348	1	2709	590	1	10.8	494	7.4	29.2	11.2	M 240	M 692	M 20			
42	80351	1	2483	185	1	17.6	503	3.6	6.3	2.65	P 176	P 65	P 4	0.260	2.190	0.320
43	80352	1	670	100	*1	17.6	503	3.6	6.3	2.65	F 171	F 28	F 3	0.230	5.410	0.240
2042	80351	1	3153	185	1	17.6	503	3.6	6.3	2.65	M 187	M 51	M 5			
44	80352	1	353	105	8	2.0				.2						
45	80352	1	942	120	1	2.2	165	1.6	2.5	.1						
2044	80352	1	1295	120	8	4.2				.2	M 47	M 140	M 6			
46	80354	1	152	95	1	1.4	20		5.6	1.65						
47	80355	1	181	80	1	1.8	238	1.1	2.8	.6						
48	81356	1	348	42	9	3.2					M 114	M 147	M 10			
49	81361	1	2107	105	8	10.6					P 37	P 46	P 5	0.172	4.260	0.910
50	81362	1	110	32	*8	10.6					F 68	F 71	F 5			
51	81362	1	158	70	1	1.0	115	1.3	5.0		F 124	F 190	F 8			

Catchment: MAUREPAS

NUM	DATE	CD	VF m3	QMAX l/s	CP	HP mm	DP mJ	IM 2I mm/h	IM 4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
52	81363	1	5259	290	1	19.0	791	4.6	5.4	.65	M 35	M 81	M 5	0.192	6.670	1.000
53	81364	1	102	50	1	.4	41	.4	.4	.1						
54	82000	1	140	55	1	1.4	164	.9	1.2	.55						
55	82003	1	54	30	1	.6	7		3.6	3.45						
56	82004	1	1544	210	1	7.4	273	3.8	6.0	.65	P 104	P 181	P 9	0.319	4.330	1.010
2055	82003	1	1598	210	1	8.0	280		6.0	3.45	M 109	M 193	M 11			
57	82004	1	193	90	1	1.0	19	.	4.2	.1	F 77	F 143	F 10			
58	82005	1	103	50	-1	.8	81	1.3	4.9	.3	F 42	F 64	F 7			
59	82005	1	67	30	-1	.8	81	1.3	4.9	.3	F 18	F 14	F 6			
3057	82004	1	353	90	1	1.8	100		4.9	.1	M 61	M 73	M 6			
60	82007	2	149	35	0						F 92	F 149	F 7			
61	82008	2	5248	220	0						F 44	F 69	F 3	0.235	6.720	1.410
62	82009	1	2279	90	0											
3060	82007	2	7676	220	0						M 52	M 55	M 3			
63	82010	1	1799	75	0						M 45	M 39	M 3	0.173		
64	82011	1	210	25	0											
65	82014	1	155	25	0						F 96	F 77	F 15			
66	82015	1	230	40	0						F 71	F 70	F 7	0.650	6.990	0.480
2065	82014	1	429	40	0						M 61	M 62	M 7			
67	82021	1	32	55	1	1.4	63	1.7	4.2		F 217	F 365	F 20			
68	82025	1	449	110	1	2.6	90	2.7	3.7	4.15	F 294	F 566	F 23	0.950	3.420	4.550
69	82026	1	401	170	1	2.0	39	2.5	3.7	.5	F 223	F 369	F 20	0.680	2.650	0.310
70	82026	1	609	175	-1	3.4	168	2.7	4.2	.1	F 83	F 131	F 10	0.360	2.860	0.290
71	82026	1	87	25	-1	3.4	169	2.7	4.2	.1	F 63	F 81	F 8			
4068	82025	1	1545	175	1	8.0	297	2.7	4.2	4.15	M 193	M 347	M 15			
72	82037	1	109	60	1	1.0	20		2.8	11.05						
73	82037	1	29	30	1	.6	10		2.5	.35						
74	82038	1	319	100	1	2.4	107	2.2	2.8	.25						
3072	82037	1	456	100	1	4.0	137		2.8	11.05	M 138	M 214	M 43			

Catchment: MAUREPAS

NUM	DATE	CD	VR m3	QMAX l/s	CP	HP mm	DP mJ	IM/21 mm/h	IM/4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
75	82043	1	1536	140	1	9.4	413	2.7	2.7	5.5	P 65	P 91	P 10	0.280	2.310	0.900
76	82044	1	39	30	+1	9.4	413	2.7	2.7	5.5						
77	82047	1	805	220	0					3.9	P 173	P 228	P 23	0.600	3.580	2.680
78	82049	1	71	30	0						F 134	F 151	F 15			
79	82059	0			1	2.6	62	4.8	17.7							
80	82061	1	824	340	1	5.4	154	5.6	20.8	2.05	P 237	P 450	P 21	0.774	2.910	0.960
81	82067	1	428	50	1	4.0	175	1.6	1.6	5.4						
82	82068	1	854	130	1	6.4	298	2.8	5.0	.75	P 81	P 126	P 13	0.375	1.750	1.360
83	82068	1	618	300	1	3.6	51	5.4	16.7	.15	F 205	F 476	F 24	0.511	3.160	0.580
84	82069	1	147	70	1	2.0	80	3.6	12.5	.2						
85	82069	1	106	50	1	1.0	19		5.1	.45						
3063	82068	1	871	300	1	6.6	150		16.7	.15	M 172	M 360	M 20			
86	82070	1	224	65	1	1.8	67	1.6	1.7	1.05	F 97	F 227	F 19	0.378		
87	82074	1	1043	215	1	7.0	112	5.2	8.0	3.4	P 63	P 97	P 11	0.370	1.480	0.970
88	82075	1	122	55	1	1.4	51	1.5	1.8	.95	F 51	F 55	F 11			
89	82075	1	210	115	1	2.2	39	2.8	4.2	.45	F 119	F 140	F 16	0.332	4.180	2.400
90	82078	1	102	40	1	.8	24	1.5	2.8	2.5						
91	82078	1	62	40	-1	.8	13		3.3	.1						
92	82080	1	47	25	1	.6	16		1.6	2.05						
3090	82078	1	211	40	-1	2.2	53		3.3	2.5	M 84	M 107	M 14			
93	82087	2	1177	240	1	6.4	95	5.0	6.3	7.35	P 194	P 263	P 29	0.832	8.700	3.020
94	82089	1	124	50	1	1.8	164	1.2	1.2	1.8	F 162	F 200	F 39			
95	82090	2	1637	160	1	8.0	329	2.6	4.2	.95	P 46	P 54	P 9	0.395	5.120	2.160
96	82095	2	470	90	1	2.4	104	1.6	2.8	4.2	F 92	F 98	F 19	0.693	9.510	2.920
97	82124	1	68	50	1	1.2	45	1.7	6.3	29.35	F 590	F 818	F 110			
98	82127	1	3752	170	1	22.6	885	3.2	4.2	2.2	P 49	P 68	P 8	0.270	4.790	0.770
99	82128	1	183	50	1	1.6	90	1.2	1.2	.55	F 43	F 41	F 6	0.352	14.600	0.510
3098	82127	1	3935	170	1	24.2	975	3.2	4.2	2.2	M 54	M 72	M 8			
100	82136	2	12495	1800	1	47.4	861	27.2	51.6	8.2	M 125	M 478	M 15	1.230	8.050	1.770

Catchment: MAUREPAS

N.S	DATE	CP	VR m3	QMAX l/s	CP	HP mm	DP mn	IM 21 mm/h	IM 4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
101	82139	1	575	75	1	4.0	174	1.9	3.1	1.65	F 41	F 44	F 6	0.255	6.740	0.690
102	82141	1	145	40	1	1.6	110	.7	.7	1.8	F 54	F 43	F 10			
103	82141	1	438	170	1	3.4	183	3.0	8.3	.45	F 129	F 237	F 19	0.472	3.000	0.510
104	82142	1	1354	200	-1	10.6	413	3.5	8.3	.4	F 35	F 54	F 5	0.148	2.810	0.690
105	82142	1	471	120	-1	10.6	413	3.5	8.3	.4	F 41	F 59	F 6	0.162	4.010	1.410
4102	82141	1	2409	200	1	15.6	706	3.5	8.3	1.8	M 50	M 67	M 6			
106	82146	1	208	125	1	1.4	5		13.2	3.65	F 106	F 222	F 21	0.959		
107	82150	1	782	480	1	5.2	92	8.1	26.0	4.6	M 152	M 256	M 14	0.465	4.820	0.980
108	82153	1	5736	2820	1	26.6	129	28.2	50.0	2.6	F 117	F 364	F 9	0.681	4.410	1.500
109	82160	1	1842	1640	8	9.4				6.95	M 132	M 419	M 19	0.323	5.380	1.320
110	82162	1	634	435	1	4.2	14		28.2	1.2	F 76	F 246	F 10	0.311	3.810	2.660
111	82162	1	55	35	1	.6	6		4.2	.7						
112	82163	2	76	45	1	1.2	56	1.3	4.4	.25	F 108	F 121	F 22			
3110	82162	2	765	435	1	6.0	76		28.2	1.2	M 72	M 143	M 18			
113	82166	2	218	85	1	2.4	72	2.8	4.2	3.45	F 109	F 148	F 22	0.307	7.330	1.100
114	82172	1	3112	455	1	17.2	107	8.0	13.9	5.8	M 65	M 133	M 13	0.208	2.710	1.320
115	82173	1	145	95	1	1.4	5		13.5	1.35	F 130	F 222	F 21	0.359		
116	82176	1	2420	1440	1	12.6	21	25.0	38.3	2.75	M 105	M 369	M 12	0.384	2.680	0.910
117	82179	1	483	310	1	4.0	112	7.1	24.0	2.9	M 97	M 177	M 13	0.449	3.820	0.570
118	82194	1	7279	2530	1	35.8	142	27.3	58.3	14.4	M 34	M 357	M 8	0.508		
119	82195	1	295	75	1	3.2	159	2.8	2.8	1.2	F 52	F 82	F 7	0.183	7.150	0.290
120	82201	1	2322	310	1	17.0	209	6.2	8.3	6.3	M 38	M 78	M 6	0.330	8.640	2.180
121	82210	1	970	350	1	7.0	126	5.0	10.0	8.35	M 90	M 158	M 15	0.361	5.090	1.190
122	82213	1	665	255	2	4.2	53	5.6	6.5	3.25	M 80	M 173	M 15	0.288	6.940	1.350
123	82216	1	247	80	1	1.0	36	1.2	1.2	2.3	F 89	F 162	F 15	0.257	9.680	5.120
124	82225	2	140	70	2	1.0	33	1.4	2.4	10.25	F 346	F 890	F 52	0.815		
125	82230	2	310	90	1	1.8	102	2.0	3.6	3.55	F 130	F 196	F 35	0.347	6.840	1.680
126	82242	1	1314	400	2	9.0	70	10.6	17.6	12.15	F 128	F 198	F 29	0.384	3.450	0.950
127	82262	1	438	460	2	4.4	97	8.1	37.5	20.25	F 442	F 894	F 110	0.841	3.090	0.570

Catchment: MAUREPAS

NUM	DATE	CD	VR m3	QMAX l/s	CP	HP mm	DP mJ	IM/21 mm/h	IM/4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
128	82263	1	485	165	*1	4.6	164	4.8	15.6	1.2	102	F 123	F 27	0.547	5.850	0.210
129	82264	1	78	40	*1	4.6	164	4.8	15.6	1.2	F 44	F 27	F 12			
128	82263	1	563	165	1	4.6	164	4.8	15.6	1.2	M 88	M 100	M 20			
130	82267	1	330	135	*2	6.6	296	4.4	6.9	3.2	F 76	F 136	F 15	0.208	5.280	0.250
131	82267	1	446	230	*2	6.6	296	4.4	6.9	3.2	F 46	F 77	F 7	0.140	3.370	0.210
132	82267	1	865	95	2	6.8	456	2.0	2.1	.2	F 44	F 38	F 7	0.129	5.780	0.350
130	82267	1	1641	230	2	13.4	752	4.4	6.9	3.2	M 44	M 52	M 5			
133	82269	1	1334	400	2	7.4	111	7.4	12.5	1.55	M 69	M 126	M 13	0.204	3.900	0.280
134	82271	1	309	250	*1	16.8	375	5.6	20.8	1.95	F 124	F 268	F 25	0.402	4.690	0.640
135	82271	1	2379	170	*1	16.8	375	5.6	20.8	1.95	F 19	F 38	F 5	0.385	4.080	0.350
134	82271	1	2688	250	1	16.8	375	5.6	20.8	1.95	M 32	M 101	M 8	- -		
136	82274	2	331	140	1	3.4	98	4.1	4.8	2.85	F 77	F 152	F 17	0.300	6.220	0.500
137	82276	2	2952	300	2	18.0	363	6.3	6.7	1.7	M 25	M 52	M 7	0.114	3.200	0.270
138	82277	1	353	120	1	2.4	58	3.2	6.0	.4	F 75	F 100	F 18	0.307	5.850	0.460
139	82277	1	625	180	1	3.2	39	3.7	7.5	.1	F 34	F 61	F 7	0.155	3.090	0.330
140	82278	1	730	155	1	4.2	124	3.2	3.3	.7	F 39	F 68	F 6	0.175	4.410	0.270
138	82277	1	1708	180	1	9.8	221	3.7	7.5	.4	M 28	M 59	M 8			
141	82278	1	152	35	1	1.4	121	.8	.8	.2	F 51	F 84	F 10			
142	82283	2	262	40	1	2.4	211	1.2	1.4	4.2	F 106	F 143	F 31			
143	82283	1	1292	170	1	8.2	152	3.8	3.8	.1	F 41	F 75	F 9	0.186	2.160	0.270
142	82283	2	1554	170	1	10.6	363	3.3	3.8	4.2	M 48	M 47	M 10			
144	82284	1	1193	140	0					1.0	F 40	F 58	F 10	0.233	3.490	0.330
145	82285	1	419	60	0					.4	F 27	F 34	F 5	0.160	5.820	0.390
144	82284	1	1612	140	0					1.0	M 36	M 50	M 7			
146	82285	1	104	40	0					.1	F 58	F 72	F 11			
147	82286	1	781	155	0					.8	F 74	F 109	F 13	0.246	7.380	0.120
146	82285	1	885	155	0					.1	M 63	M 100	M 10			
148	82286	1	97	40	9	1.3				.25	F 58	F 60	F 10			
149	82290	2	441	245	1	3.0	50	4.6	6.1	3.4	M 126	M 195	M 30	0.284	7.240	0.120

Catchment: MAUREPAS

NUM	DATE	CD	VP m3	QMAX l/s	CP	HP mm	DP m3	IM 2I mm/h	IM 4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
150	82294	1	5525	310	1	29.4	621	5.4	7.3	4.25	M 36	M 59	M 9	0.178	11.600	0.700
151	82310	1	162	45	0					15.2						
152	82310	1	211	60	0					.4						
153	82310	1	4821	430	0					.1						
3151	82310	1	5194	430	8	26.2				15.2	M 84	M 178	M 18	0.235	3.660	0.700
154	82313	1	340	95	1	2.4	58	1.9	1.9	2.35	M 79	M 99	M 16	0.213	8.430	2.360
155	82315	1	1544	360	1	8.8	201	6.7	9.7	1.8						
156	82317	1	455	165	1	3.2	106	4.0	6.9	1.9						
2155	82315	1	1999	360	1	12.0	307	6.7	9.7	1.8	M 75	M 139	M 14	0.322	3.070	0.800
157	82319	1	972	55	8	4.8				1.75	M 66	M 66	M 16	0.217	6.580	1.500
158	82320	2	761	75	1	3.8	270	1.4	1.4	1.0	M 44	M 40	M 11	0.230	4.970	1.270
159	82325	1	540	60	1	3.8	164	2.4	4.2	4.25	M 90	M 73	M 21	0.367	6.270	1.110
160	82327	1	822	110	1	5.4	162	3.3	9.4	1.65	M 52	M 112	M 13	0.204	3.660	0.700
161	82329	1	933	160	1	5.4	222	3.8	5.7	1.7	M 33	M 43	M 10	0.207	5.050	0.410
162	82338	1	3696	285	1	19.6	452	5.6	6.7	9.65	M 39	M 61	M 8	0.278	3.180	0.170
163	82339	1	175	45	1	1.0	68	.6	.6	.15						
164	82340	1	468	95	1	3.4	198	2.2	2.8	1.05						
165	82340	1	241	140	1	1.6	60	2.3	6.7	.15						
166	82341	1	53	35	1	.6	12		4.2	.3						
4163	82339	1	937	140	1	6.6	338	2.3	6.7	.15	M 90	M 135	M 10	0.344	9.840	0.230
167	82342	1	352	75	9	2.6				.9	M 55	M 52	M 7	0.237	7.870	0.060
168	82345	1	1146	160	1	6.2	179	3.0	4.2	2.75						
169	82345	1	254	160	1	1.8	73	3.2	9.4	.3						
2168	82345	1	1400	160	1	8.0	252	3.2	9.4	2.75	M 58	M 63	M 5	0.226	5.050	0.340
170	82347	1	1531	110	1	8.0	348	2.2	2.3	2.2						
171	82349	1	647	460	1	3.6	108	6.0	17.1	.95						
172	82349	1	5017	1220	1	20.2	491	14.8	52.1	.15						
173	82350	1	565	155	1	3.0	179	3.6	6.3	.35						
174	82350	1	375	140	1	1.8	114	1.7	1.7	.15						

Catchment: LES ULIS

NUM	DATE	CD	VR m3	QMAX l/s	CF	HP mm	DP mn	IM/31 mm/h	IM/4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	PT mg/l	NO3 mg/l	N-NH4 mg/l
1	81356	1	343	38	1	3.0	441	.8	1.0	.	F 149	F 176	F 22			
2	81361	1	1993	80	1	11.6	687	1.6	2.1	4.6	M 88	M 117	M 28	0.181	4.190	1.000
3	81363	2	7927	520	1	24.8	768	6.1	18.8	1.15	M 135	M 115	M 19	0.322	6.910	1.240
4	82004	1	3805	535	1	11.4	773	5.9	18.8	5.0	M 212	M 555	M 27	0.382	4.520	0.580
5	82008	1	3583	225	2	7.0	601	3.2	4.5	3.1	P 104	P 158	P 19	0.142	6.200	1.830
6	82010	1	3403	195	0					1.4						
7	82021	1	49	35	1	1.8	101	1.5	3.3	10.5	F 1850	F 1660	F 465			
8	82025	1	335	80	1	2.8	120	2.1	4.7	4.15	F 730	F 1030	F 109	1.250	2.500	3.400
9	82026	1	166	70	1	1.6	39	2.0	3.1	.45	F 320	F 558	F 50			
10	82026	1	715	95	1	3.8	149	2.4	3.1	.15	F 112	F 186	F 18	0.240	5.000	0.480
3008	82025	1	1216	95	1	8.2	308	2.4	4.7	4.15	M 239	M 360	M 38			
11	82037	1	46	30	1	1.6	32	2.1	4.8	11.05						
12	82038	1	31	25	1	1.2	35	1.6	4.2	.65						
2011	82037	1	77	30	1	2.8	67	2.1	4.8	11.05	M 521	M 691	M 152			
13	82043	1	769	80	1	8.4	451	2.1	2.1	5.5	M 209	M 225	M 52	0.290	3.670	3.300
14	82048	1	222	110	1	4.8	388	2.2	4.8	3.9	F 476	F 618	F 130	0.730		
15	82049	1	62	30	8	2.4				.85	M 372	M 512	M 78			
16	82061	1	990	320	1	7.0	172	5.1	15.6	12.4	F 846	P 1960	P 159	1.920	3.900	2.170
17	82067	1	182	40	1	3.2	145	1.6	3.3	5.45	F 338	F 307	F 104	0.550		
18	82068	1	792	150	1	6.0	193	3.2	8.3	.75	P 186	P 304	P 35	0.451	4.130	0.510
19	82068	1	775	240	1	4.4	67	5.1	7.1	.3	P 201	P 467	P 29	0.396	4.580	1.790
20	82070	1	391	120	1	3.2	69	2.5	4.9	1.9	M 139	M 211	M 26	0.208	4.320	2.210
21	82074	1	800	150	1	6.0	131	4.7	6.9	3.45	P 169	P 260	P 38	0.210	3.380	3.800
22	82074	1	28	30	1	1.0	41	1.3	6.8	.7	F 350	F 312	F 60			
23	82075	1	524	180	1	3.8	123	3.0	8.3	.7	M 248	M 745	M 35	0.508	3.410	1.980
24	82087	1	397	135	1	4.6	102	4.2	10.4	12.0	M 771	M 992	M 134	1.120	11.200	7.120
25	82089	1	103	40	+1	3.6	142	1.7	1.9	1.8	F 308	F 375	F 68			
26	82089	1	80	25	+1	3.6	142	1.7	1.9	1.8	F 136	F 150	F 24			
2025	82089	1	183	40	1	3.6	142	1.7	1.9	1.8	M 152	M 134	M 32			

NUM	DATE	CD	VS m3	QMAX l/s	CP	HP mm	DP mJ	IM 31 mm/h	IM 4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
27	82090	1	372	105	-1	5.8	332	2.2	3.2	1.0	F 172	F 228	F 35	0.411	7.830	0.880
28	82091	1	163	45	-1	5.8	332	2.2	3.2	1.0	F 36	F 40	F 6			
2027	82090	1	535	105	1	5.8	332	2.2	3.2	1.0	M 126	M 170	M 24			
29	82095	1	280	50	1	3.8	149	1.9	4.2	4.15	F 271	F 217	F 68	0.311	8.530	5.700
30	82118	1	55	35	1	2.0	36	2.6	6.0	23.45	F 2720	F 2480	F 666			
31	82124	1	74	55	1	1.4	11		7.1	6.05	F 749	F 883	F 131			
32	82127	1	2140	130	1	20.6	714	2.2	3.2	2.05	F 123	F 141	F 23	0.229	14.100	4.270
33	82136	1	185	75	1	2.4	16		10.7	9.05	F 924	F 1010	F 327			
34	82137	1	770	105	1	6.0	148	2.6	2.8	.55	F 173	F 277	F 30	0.356	5.610	2.370
2033	82136	1	955	105	1	8.4	164		10.7	9.05	M 252	M 330	M 45			
35	82139	1	174	35	1	3.4	165	1.5	1.5	1.65	F 159	F 146	F 35	0.264		
36	82141	1	2357	770	1	12.0	146	8.2	35.0	2.4	F 320	F 1200	F 56	1.080	4.210	3.220
37	82142	1	1282	150	1	7.2	183	3.0	3.0	.55	F 63	F 180	F 9	0.273	3.840	1.120
38	82142	1	632	240	1	3.0	52	3.6	11.7	.1	F 121	F 475	F 14	0.298	4.230	0.770
3036	82141	1	4271	770	1	22.2	381	8.2	35.0	2.4	M 227	M 836	M 30			
39	82151	1	164	75	1	2.2	35	2.8	5.1	8.3	F 1120	F 778	F 234			
40	82151	1	778	235	1	6.6	105	7.3	23.3	.55	M 221	M 457	M 29	0.570	5.400	1.210
41	82153	1	109	50	1	1.6	39	1.8	2.8	1.4						
42	82153	1	260	55	2	.8	9		3.7	.65						
43	82154	1	43	30	0					.6						
3041	82153	1	412	55	9	2.6				1.4	M 116	M 188	M 26			
44	82154	1	328	165	1	4.8	11		20.0	.45	F 301	F 564	F 41	0.500	5.440	2.460
45	82160	1	2320	1145	1	10.8	37	14.4	54.2	5.9	M 373	M 1230	M 33	0.822	6.510	2.280
46	82163	1	165	100	1	1.2	10		6.3	2.95	F 194	F 234	F 34			
47	82164	1	41	30	1	1.0	98	.9	2.8	.25	F 104	F 44	F 18			
2046	82163	1	206	100	1	2.2	108		6.3	2.95	M 247	M 540	M 40			
48	82166	1	114	60	1	1.4	36	1.8	6.3	2.45	F 450	F 304	F 79			
49	82172	1	1728	390	1	10.4	112	6.7	8.3	5.8	P 212	F 329	P 44	0.402	4.310	2.100
50	82178	1	225	115	1	2.2	14		15.6	6.15	F 701	F 808	F 186	1.100		

Catchment: LES ULIS

NUM	DATE	CP	VR m3	QMAX l/s	CP	HP mm	DP mJ	IM 3I mm/h	IM 4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
51	82181	1	1211	620	1	6.8	34	8.9	29.9	4.3	M 356	M 1260	M 37	0.616	4.360	2.480
52	82194	1	2612	1040	1	13.0	69	8.8	31.7	11.1	F 179	F 443	F 28	0.380	4.900	4.000
53	82195	1	540	210	1	4.4	142	4.7	8.3	1.15	F 101	F 113	F 17	0.147	3.200	2.050
2052	82194	1	3222	1040	1	17.4	211	8.8	31.7	11.1	M 365	M 678	M 58			
54	82201	0			1	79.6	230	93.7	208.4	6.35						
55	82210	1	1347	230	1	8.8	118	5.9	14.6	8.35	M 266	M 556	M 49	0.345	4.700	2.220
56	82213	2	907	210	1	6.2	49	7.3	19.8	3.25	M 195	M 429	M 34	0.306	7.150	2.080
57	82216	1	154	130	1	.8	12		6.3	2.95	F 307	F 1520	F 48			
58	82242	1	742	250	9	6.8				25.4	M 565	M 900	M 127	0.369	5.190	2.640
59	82261	1	383	175	1	3.8	37	3.8	9.4	19.2	M 1490	M 1400	M 273	1.100	4.780	7.810
60	82263	1	351	105	1	4.6	165	2.5	9.0	2.2	M 277	M 353	M 60	0.504	4.240	1.810
61	82267	1	201	80	+1	5.0	206	2.7	3.2	3.1	F 413	F 253	F 79			
62	82267	1	119	45	+1	5.0	206	2.7	3.2	3.1	F 143	F 88	F 26			
63	82267	1	2306	210	1	12.8	366	3.8	8.3	.35	P 99	P 163	P 16	0.135	5.540	1.010
3061	82267	1	2625	210	1	17.3	572	3.8	8.3	3.1	M 106	M 159	M 21			
64	82269	2	821	290	1	5.8	106	5.8	9.5	1.65	M 216	M 364	M 40	0.208	3.400	1.230
65	82271	1	2855	490	1	20.0	444	3.2	56.3	1.9	P 113	P 445	P 21	0.229	3.930	0.720
66	82275	1	286	80	2	3.0	64	2.5	4.2	2.9	F 229	F 246	F 126	0.527		
67	82276	1	1659	195	1	14.6	330	4.2	5.1	1.65	M 64	M 131	M 22	0.124	2.880	0.890
68	82277	1	481	145	1	3.0	30		9.3	.45	M 129	M 382	M 22	0.260	3.250	0.890
69	82277	1	932	190	1	4.8	85	4.1	12.3	.1	F 93	F 306	F 17	0.238	3.200	0.460
70	82278	1	1444	235	2	7.4	157	3.9	4.9	.55	F 53	F 107	F 11	0.139	2.430	0.520
2069	82277	1	2376	235	2	12.2	242	4.1	12.3	.1	M 63	M 218	M 12			
71	82278	1	387	50	9	2.8				.2	M 77	M 206	M 13	0.244	5.960	0.770
72	82283	1	489	170	2	4.6	122	4.0	8.3	4.2	F 232	F 396	F 75	0.298	3.470	2.760
73	82283	1	2309	230	9	10.8				.2	P 72	P 226	P 15	0.141	2.530	0.640
2072	82283	1	2796	280	9	15.4				4.2	M 83	M 184	M 23			
74	82284	1	1409	155	1	8.4	202	3.1	4.2	1.05	F 87	F 390	F 20	0.214	2.880	0.640
75	82285	1	105	40	0					.3						

Catchment: LES ULIS

NUM	DATE	CD	VR m3	QMAX l/s	CP	HP mm	DP mn	IM 31 mm/h	IM 4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
76	82285	1	798	80	0					.05	F 42	F 92	F 10	0.127	4.360	0.770
77	82285	1	284	110	0					.05	F 119	F 438	F 24			
1074	82284	1	2596	155	.9	15.1				1.05	M 64	M 212	M 13			
78	82286	2	385	160	1	4.0	107	3.4	18.8	.95						
79	82290	1	394	175	1	3.0	47	3.5	10.7	3.75	F 353	F 790	F 112		4.020	4.890
80	82294	1	6194	280	1	30.0	611	4.5	7.0	4.25	M 56	M 146	M 20	0.138	5.620	1.380
81	82311	2	3001	520	1	16.0	385	7.9	10.4	15.6	F 153	F 408	F 45	0.107		
82	82313	1	420	100	1	4.6	268	2.6	3.6	2.45	M 224	M 428	M 45	0.311		
83	82315	1	1270	175	1	8.0	202	3.9	6.0	1.6	M 120	M 244	M 26	0.198		
84	82319	1	220	40	+1	6.0	532	1.4	3.3	3.65						
85	82319	1	526	70	+1	6.0	532	1.4	3.3	3.65						
084	82319	1	746	70	1	6.0	532	1.4	3.3	3.65	M 127	M 242	M 94	0.203		
86	82320	1	548	50	1	4.2	304	1.4	1.4	.9	M 92	M 120	M 15	0.124		
87	82325	0			1	3.6	223	1.2	1.7	4.15						
88	82327	0			1	5.8	204	2.7	10.4	1.55						
89	82328	0			1	8.4	274	4.2	6.0	1.65						
90	82338	1	4427	360	1	22.8	421	6.0	8.3	9.7	F 92	F 215	F 25	0.107		
91	82340	1	631	90	1	4.0	195	2.2	3.2	1.25	M 231	M 662	M 35	0.398		
92	82341	1	98	40	1	2.0	125	1.3	2.3	.9						
93	82342	1	37	30	1	1.8	104	1.3	1.3	.4						
092	82341	1	135	40	1	3.8	229	1.3	2.3	.9	M 137	M 170	M 24	0.185		
94	82345	1	1169	210	1	7.2	169	3.9	8.3	2.85	M 133	M 300	M 20	0.208		
95	82348	5	1539		1	8.6	465	2.0	2.4	2.6						
96	82349	5	390		1	2.6	169	3.0	15.4	.8						
97	82349	5	1340		1	18.6	475	7.8	33.3	.2						

Catchment: AIX-ZUP

NUM	DATE	CD	VR m3	QMAX l/s	CP	HP mm	DP mJ	IM/14 mm/h	IM/4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
1	80284	1	1369	802	1	7.2	210	6.2	6.4		F 409	F 960	F 74	0.004	14.400	4.300
2	80288	1	69	27	1	.8	12		2.8	4.4						
3	80289	1	1121	604	1	9.8	121	15.1	37.1	1.35	F 695	F 702	F 36	0.070	60.200	1.400
4	80297	1	598	108	1	6.6	126	8.3	14.6	7.65	F 503	F 233	F 13	0.060	5.300	4.100
5	80307	0			1	5.4	565	2.6	7.6	9.35						
6	80309	0			1	19.6	166	9.0	10.4	2.05						
7	80313	1	1394	105	1	14.6	603	5.1	6.3	3.25	F 115	F 222	F 11	0.040	3.800	0.300
8	80316	1	208	56	1	1.2	100	3.0	7.3	2.6	F 102	F 112	F 10	0.040	4.700	1.910
9	80316	1	529	60	1	4.2	174	4.0	6.3	.2	F 67	F 68	F 5	0.050	7.100	1.200
008	80316	1	737	60	1	5.4	274	4.0	7.3	2.6	M 98	M 104	M 8			
10	80330	1	335	130	1	4.2	85	6.6	11.1	13.65	F 652	F 804	F 64	0.040		
11	80340	1	54	27	1	1.0	5		9.4	9.9						
12	80351	1	630	66	1	7.4	273	1.9	2.4	20.9	F 359	F 295	F 27		1.300	5.200
13	81009	1	408	24	3	3.0	221	1.8	1.8	14.15						
14	81011	1	873	80	1	11.6	294	3.7	3.9	1.6						
15	81012	1	292	39	1	2.4	162	2.0	2.6	.25	F 408	F 63	F 11	0.024	4.600	1.470
16	81019	1	253	46	1	3.8	189	2.4	6.3	6.8	F 276	F 170	F 32		2.640	1.620
17	81034	1	62	15	1	1.2	89	1.3	2.1	14.7						
18	81049	1	140	15	0					15.5	F 92	F 22		0.050	6.200	4.400
19	81056	1	106	12	1	1.0	138	1.1	1.1	6.05						
20	81057	1	907	40	1	7.8	449	1.8	1.8	1.5	F 500	F 186	F 85	0.046	5.620	1.300
21	81064	2	1375	140	1	11.4	312	4.8	6.7	6.2						
22	81073	1	280	23	1	4.4	276	2.0	2.1	3.7	F 269	F 140	F 42	0.120	4.300	3.300
23	81084	1	167	25	1	2.2	112	3.6	4.2	10.75						
24	81086	2	43	10	1	1.8	150	1.4	1.5	2.15						
25	81087	2	4167	610	1	27.6	1063	13.5	25.4	.75						
26	81088	1	3760	195	1	25.8	1322	6.7	8.3	.3	F 45	F 98	F 5	0.070	3.620	2.160
27	81090	1	1001	90	1	9.4	305	3.0	3.6	.75	F 41	F 65	F 3	0.060	2.760	0.140
28	81113	1	926	70	1	13.2	614	2.5	2.6	21.9	F 140	F 319	F 54	0.083	10.300	0.940

Catchment: AIX-ZUP

NUM	DATE	CD	VR m3	QMAX l/s	CF	HP mm	DP mn	IM 14 mm/h	IM 4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
29	81113	1	285	18	-1	13.2	614	2.5	2.6	21.9						
30	81115	1	543	350	1	5.6	68	12.9	25.0	1.25	F 370	F 976	F 127	0.075	[illegible]	0.680
31	81115	1	500	90	1	4.0	119	3.7	4.2	.2	F 54	F 56	F 13	0.074	5.100	0.470
2020	81115	1	1043	350	1	9.6	187	12.9	25.0	1.25	M 215	M 620	M 77			
32	81129	1	345	82	1	3.6	163	5.0	5.2	13.85	F 253	F 595	F 49	0.040	4.370	1.150
33	81129	1	1793	280	1	12.6	241	9.0	15.6	.1	P 58	P 245	P 9	0.042	2.950	0.140
34	81129	1	871	425	1	6.0	189	12.3	25.0	.15	P 83	P 389	P 11	0.085	2.450	0.100
2032	81129	1	3009	425	1	22.2	593	12.3	25.0	13.85	M 115	M 365	M 15			
35	81130	1	277	75	1	3.6	190	5.4	12.2	.7	F 244	F 239	F 47	0.040	2.170	0.180
36	81136	1	827	320	1	8.8	152	11.1	16.7	5.15	F 158	P 449	P 25	0.028	3.060	0.360
37	81141	1	175	60	1	3.0	184	3.7	8.3	4.6	F 217	F 388	F 54	0.062	1.950	0.180
38	81144	1	438	40	1	4.2	452	2.4	3.6	3.75	F 320	F 182	F 55	0.032	2.300	0.310
39	81145	1	58	17	1	1.0	163	1.1	2.4	.5						
40	81175	1	534	590	1	4.8	9		22.2	29.75	P 760	P 2010	P 153	0.110	0.190	0.850
41	81178	1	939	280	1	9.6	115	11.8	16.7	2.55	P 141	P 259	P 29	0.260	2.920	0.070
42	81178	1	2039	1050	1	13.6	132	17.3	31.3	.2	P 198	P 757	P 21	0.045	1.970	0.090
2041	81178	1	2978	1050	1	23.2	247	17.3	31.3	2.55	M 198	M 546	M 22			
43	81197	1	2861	380	1	26.4	446	11.3	13.1	19.3	P 130	P 235		0.045	2.840	0.240
44	81204	1	265	56	1	3.2	106	2.6	2.7	5.9	F 177	F 306	F 47	0.080	5.930	6.770
45	81246	1	27	20	1	1.6	18	4.2	6.3	42.2						
46	81251	1	129	30	1	2.6	275	1.6	2.2	5.1						
47	81252	1	480	80	1	3.8	219	3.9	5.0	.4	P 454	P 570	P 127	0.262	5.910	0.820
48	81255	1	154	60	1	1.4	28	3.4	9.4	2.5	F 803	F 860	F 256	0.325	0.830	0.820
49	81255	1	56	17	1	.4	23	.7	.7	.1						
50	81261	2	5330	2400	1	37.0	134	68.0	132.6	5.8	M 614	M 612				
51	81264	1	28	15	2	1.6	39	2.4	4.6	3.5						
52	81268	1	458	60	2	5.0	405	3.6	4.2	4.0						
53	81269	1	56	40	2	1.4	9		8.3	.55						
54	81270	1	105	40	0					.4						

NUM	DATE	CD	VR m3	QMAX l/s	CP	HP mm	DP mJ	IM/14 mm/h	IM/4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
3052	81268	1	619	60	0					4.0	M 901	M 284	M 291			
55	81274	1	869	230	1	7.4	221	6.5	6.5	1.8	P 138	P 195	P 30	0.256	2.350	0.580
56	81297	-1	744	120	3	8.6	207	5.0	7.6	23.65	P 281	P 188	F 127	0.086	4.660	0.790
57	81339	1	56	13	1	2.2	227	2.2	2.2	41.7						
58	81345	1	169	50	1	1.2	23	3.0	4.2	4.8	F 1220	F 437	F 460		1.180	1.560
59	81345	1	2397	325	1	17.8	351	8.9	9.1	.6	P 250	P 207	P 44		3.890	0.630
60	81346	1	1977	110	1	13.8	448	5.0	5.4	.7						
3058	81345	1	4543	325	1	32.8	822	8.9	9.1	4.8	M 161	M 131	M 39			
61	81348	1	297	75	1	1.2	17	3.2	3.5	1.75	F 515	F 170	F 123		4.200	1.180
62	81350	1	6746	800	1	43.6	394	19.9	33.3	2.15	M 73	M 282	M 5	0.078	2.810	0.260
63	81351	1	269	70	1	2.4	80	3.1	6.3	.55	F 134	F 222	F 28		6.420	0.490
64	81354	1	1652	335	1	15.2	166	10.1	14.6	2.2	P 58	P 139	P 0		3.290	0.410
2063	81351	1	1921	335	1	17.6	246	10.1	14.6	.55	M 109	M 140	M 15			
65	81354	1	807	80	1	6.6	176	3.7	4.0	.1	P 46	F 79	F 0	0.062	4.120	0.680
66	81355	1	139	22	1	2.2	139	1.7	2.8	1.05	F 156	F 147	F 41		15.000	1.240
67	81357	1	934	72	1	9.0	309	2.8	4.2	1.15	M 95	M 59		0.086	3.710	0.390
68	81360	1	224	70	2	4.0	69	5.8	12.9	3.2	M 134	M 114		0.062	5.110	1.340
69	81361	1	3631	450	3	31.6	433	13.2	13.2	1.05	M 87	M 137		0.054	2.640	0.260
70	81363	1	404	85	3	4.2	164	3.3	3.3	1.3	F 108	F 130				
71	82011	1	1529	145	1	11.8	472	4.2	4.2	12.6	P 116	P 103	P 16	0.066	4.610	1.120
72	82013	1	296	55	1	2.6	71	2.4	2.6	2.0	F 160	F 190	F 16	0.186	5.930	2.300
73	82015	1	452	55	1	3.6	177	2.1	3.3	1.55	P 76	P 54	P 8	0.060	6.430	0.850
74	82026	1	669	160	1	5.2	95	4.7	4.7	10.7	P 133	P 198	F 49	0.068	5.220	1.390
75	82046	1	179	25	3	1.4	66	1.0	1.0	20.8	F 364	F 111	F 103			

Catchment: AIX-NORD

NUM	DATE	CD	VR m3	QMAX l/s	CP	HP mm	DP mJ	IM/31 mm/h	IM/4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
1	80284	1	2012	1732	3	7.2	210	4.4	6.4		M 630	M 409	M 135	0.060		
2	80289	0			3	9.8	121	7.1	37.1	5.75						
3	80297	1	579	120	3	6.6	126	3.9	14.6	7.65	F 547	F 313	F 29	0.180	4.600	0.700
4	80307	1	262	46	3	2.2	113	1.6	7.6	9.35	F 220	F 29				
5	80307	1	184	20	3	1.4	84	1.1	2.8	.1	F 211	F 113		0.260	2.800	0.540
6	80307	1	472	26	3	1.8	103	1.1	1.7	.15	F 120	F 340	F 19			
2005	80307	1	656	26	3	3.2	187	1.1	2.8	.1	M 91	M 223				
7	80309	1	5743	492	9	30.8				2.0						
8	80313	1	1425	286	1	12.2	604	4.7	8.3	3.0	F 156	F 127	F 26	0.230	2.400	1.000
9	80316	1	353	59	1	3.8	117	2.5	3.4	2.8						
10	80330	1	212	20	1	2.4	89	1.5	1.9	13.7	F 63	F 29	F 5	0.110		
11	80340	2	69	336	1	1.2	6		10.8	9.95						
12	80361	2	994	42	1	6.8	232	2.2	2.4	20.9						
13	81010	1	517	42	1	3.0	221	1.4	1.8	14.35						
14	81011	1	1258	53	1	11.2	429	2.7	3.6	1.6	F 92	F 47	F 12	0.122	4.690	0.700
15	81012	1	371	37	1	2.0	170	1.0	1.9	.1						
16	81019	1	489	40	1	3.8	186	1.8	6.7	6.85	F 155	F 264	F 20	0.062		0.430
17	81034	1	250	38	1	1.4	83	1.2	1.2	14.7	F 106	F 60	F 15	0.091		
18	81049	1	113	10	0					15.5						
19	81055	1	72	12	1	1.0	73	.9	.9	6.0						
20	81055	1	143	20	1	.8	53	.8	1.1	.2						
21	81057	0			1	7.4	380	1.5	2.1	1.6	F 86	F 95	F 19	0.172	5.380	0.320
22	81064	2	803	105	8	12.4				6.2	F 120	F 124	F 23			
23	81073	2	249	23	1	4.2	292	1.5	1.5	8.7						
24	81084	1	314	35	1	2.2	117	1.7	4.2	10.8						
25	81087	2	4474	1100	1	19.0	643	6.3	25.0	2.9						
26	81088	1	1545	470	1	10.2	321	4.6	11.9	.15	F 157	F 418	F 15	0.060	1.500	
27	81088	1	2529	220	1	24.2	1332	4.3	7.9	.35	P 71	P 113	P 8	0.150	3.100	0.070
28	81090	1	785	80	1	10.0	318	2.6	2.8	.7	F 62	F 83	F 4	0.100	3.000	0.400

Catchment: AIX-NORD

NUM	DATE	CD	VR m3	QMAX l/s	CP	HP mm	DP mJ	IM/31 mm/h	IM.4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
29	81109	1	281	40	1	1.8	126	1.3	10.4	18.65	F 1260	F 860	F 290	0.094		
30	81113	1	872	40	3	13.2	614	2.2	2.6	3.15	F 188	F 172	F 72	0.102		1.010
31	81115	1	570	280	3	5.6	68	6.5	25.0	1.25	F 668	F 374	F 200	0.090	2.800	0.760
32	81115	1	550	90	3	4.0	119	3.0	4.2	.2	F 48	F 52	F 10	0.067		
2031	81115	1	1120	280	3	9.6	187	6.5	25.0	1.25	M 235	M 284	M 87			
33	81129	1	303	80	1	3.2	52	3.7	6.0	13.95	F 487	F 396	F 68	0.140	1.570	1.010
34	81129	1	2643	680	1	14.8	227	10.1	13.5	.15	P 121	P 370	P 19	0.100	3.880	0.150
35	81129	1	901	560	1	5.0	121	4.9	16.7	.2	F 240	F 567	F 10	0.042	1.840	0.100
3033	81129	1	3847	680	1	23.0	400	10.1	16.7	13.95	M 182	M 545	M 24			
36	81130	1	308	190	1	4.0	204	3.6	8.3	.75	F 127	F 218	F 18	0.140	1.100	0.080
37	81136	1	2513	1880	1	14.8	57	14.4	62.5	5.15	P 274	P 1150	P 19	0.074	3.970	0.320
38	81141	1	217	40	1	2.6	166	2.4	8.9	4.7	F 416	F 586	F 122	0.067	0.230	0.130
39	81144	1	219	38	1	2.8	110	1.9	2.8	3.75	F 428	F 481	F 123			
40	81145	1	178	25	1	1.0	57	.7	2.8	.3						
41	81145	1	173	30	1	1.4	38	1.7	6.3	.65	F 178	F 245				
42	81175	1	644	730	1	5.4	14		45.8	29.7	F 1090	F 3780	F 243	0.277	3.570	0.070
43	81178	1	1018	700	2	9.0	292	6.6	18.3	2.45	F 361	F 492	F 36	0.214	2.790	0.020
44	81178	1	2515	1500	3	13.6	132	14.2	31.3	.15	P 217	P 853	F 20	0.047	1.530	0.070
2043	81178	1	3533	1500	3	22.6	424	14.2	31.3	2.45	M 292	M 588	M 24			
45	81197	1	1835	640	1	25.0	466	7.1	12.5	19.25	P 185	P 305		0.036	1.780	0.500
46	81204	0			3	3.2	106	2.5	2.7	5.9						
47	81252	1	125	27	1	1.6	21		4.9	48.0						
48	81252	1	147	27	1	1.8	48	1.9	2.8	.1						
49	81255	1	487	320	1	3.8	150	3.5	16.0	2.55	F 860	F 660	F 300	0.214	3.080	0.600
50	81261	2	6323	4300	1	30.0	134	32.8	88.8	5.8	P 608	P 1070		0.100	3.820	0.720
51	81263	0			8	2.6				2.3						
52	81268	0			1	2.0	272	.9	4.2	3.6						
53	81269	0			8	6.0				.7						
54	81274	2	692	180	1	8.2	199	6.0	8.3	4.0	M 396	M 256	M 138	0.170	1.280	1.550

Catchment: AIX-NORD

NUM	DATE	CD	VR m3	QMAX l/s	CP	HP mm	DP mJ	IM 31 mm/h	IM/4 mm/h	DTS Jours	DCO mg/l	MES mg/l	DBO5 mg/l	Zn mg/l	NO3 mg/l	N-NH4 mg/l
55	81298	1	477	90	1	8.6	207	4.3	7.6	23.6	M 371	M 125	M 193	0.150	0.380	1.560
56	81339	1	142	20	1	2.0	224	1.7	2.2	41.85						
57	81344	1	129	40	1	2.0	74	2.0	4.2	4.75						
58	81345	1	1984	500	1	20.2	402	7.1	12.5	.55	P 359	P 290	P 49		2.580	0.970
59	81346	1	984	65	1	13.0	443	3.1	4.2	.7	P 77	P 58	P 15		3.020	0.520
3057	81344	1	3097	500	1	35.2	919	7.1	12.5	4.75	M 403	M 216	M 112			
60	81348	1	261	45	1	3.2	113	2.5	4.2	1.65	F 583	F 295	F 150		3.770	0.790
61	81350	1	6689	1080	1	49.6	639	14.8	20.8	1.9	M 204	M 444	M 9	0.050	2.210	0.220
62	81351	1	191	60	1	3.2	50	3.6	5.2	.55	F 566	F 319	F 142		3.800	0.100
63	81354	1	1472	500	1	22.2	454	8.4	12.5	2.2	P 86	P 216	P 14		3.320	0.260
2062	81351	1	1663	500	1	25.4	504	8.4	12.5	.55	M 114	M 237	M 23			
64	81354	1	474	50	*1	22.2	454	8.4	12.5	2.2	F 65	F 62	F 0	0.090	3.470	0.070
65	81355	1	142	25	1	1.6	179	1.0	1.4	1.0	F 199	F 376	F 60		9.920	0.570
66	81357	1	603	40	1	9.2	333	2.3	3.1	1.2	M 130	M 117		0.172	3.600	0.260
67	81360	1	195	25	3	4.0	69	4.4	12.9	3.2	F 208	F 116			7.180	0.510
68	81361	1	4259	650	3	31.6	433	13.2	13.2	1.05	M 108	M 211		0.054	2.650	0.240
69	81363	1	241	45	3	4.2	164	3.3	3.3	1.3	F 173	F 176				
70	82011	0			1	12.2	456	3.6	6.1	12.6						
71	82013	1	119	20	1	3.0	77	2.4	2.8	2.0	F 512	F 400	F 52		15.500	1.020
72	82015	1	256	25	1	4.0	158	1.6	3.3	1.55	F 349	F 174	F 15	0.152	5.900	0.490
73	82026	1	316	160	1	5.8	186	4.1	5.8	10.65	P 194	P 331	P 58			

APPENDIX 2.3

Extract of a computerised type 2 file for "event mean concentrations". After the Laboratoire d'Hydrologie Mathématique (report LHM 09/1986, 1986).

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248 11 252 52 130 5 11 24 22 66 34 63 -9 -9 -9 -9 -9 -9 20954 21274 20244
033 20744 20234 25250 20080 20892 20520 22280 20780 22160 -9 -9 -9 -9
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 1380 4 11 104 -9 45 193 604 800 26 10 10 35 -9 1684 6354 214 20162 20554
094 21741 21290 20472 20130 20211 20540 21460 20054 21092 20313 20263
253 21192 20000 4 265 11 399 53 140 4 11 30 -9 41 41 73 145 83 3 96 122
 20874 20824 20144 20282 20614 20114 26320 20920 20252 20080 21670 20420
460 20523 20622 20463 20143 20113 20752 20000 2003 263 12 1910 88 1380
12 134 112 86 193 604 800 26 10 10 35 -9 1614 3374 224 182 -9 -9 -9 -9
 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 5 267 11 67 21 50 4 11 16 15 25 28
 195 24 0 115 146 -9 20614 21264 20194 20272 -9 -9 -9 -9 -9 -9 -9 -9
 -9 -9 -9 -9 -9 -9 -9 6 267 11 65 16 50 5 11 10 -9 62 14 31 35 13 2 130
0 -9 20874 21534 20244 20352 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9
 -9 7 268 11 178 34 85 5 11 18 -9 121 19 36 45 8 2 139 170 -9 20594 20964
353 20322 20494 20015 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 2006
7 12 243 50 85 5 12 28 24 183 19 36 35 13 2 130 160 -9 764 1144 25 352
 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 10008 280 11 1050 70 390
11 74 59 64 75 250 1200 15 6 2 45 190 1444 2234 364 12451 10085 10035
891 10040 10472 10120 10211 10720 11940 14052 10692 10353 10273 10024
782 10000 9 280 11
```

APPENDIX 3.1. The lognormal distribution.

The Two Parameter Lognormal Distribution

The probability density function is:

$$f(x) = \frac{1}{\sqrt{2\pi}} \cdot \frac{1}{\beta} \cdot \frac{1}{x} \; e^{\frac{-\frac{1}{2}(\ln(x) - \alpha)^2}{\beta^2}}$$

Let $z = \ln(x)$ then $h(z) = \frac{1}{\sigma_z \sqrt{2\pi}} \cdot e^{-\frac{1}{2}[(z-\mu_z)/\sigma_z]^2}$

is the equation of the normal probability density function.

The reduced variate y is related to x by: $y = x/\alpha$ and $F(x) = G(y)$ where $G(Y)$ is the cumulative probability density function of y.

Calculation of the Parameters by the Method of Moments

The parameters are estimated by the following formulas:

$$\hat{\beta} = \hat{\sigma}_z + [\ln(\hat{\sigma}_x/\bar{x})^2 + 1)]^{\frac{1}{2}}$$

$$\hat{\alpha} = \hat{\mu}_z = \ln(\bar{x}) - \frac{\hat{\beta}^2}{2}$$

Calculation of the Parameters by the Method of Maximum Likelihood

The maximum likelihood estimates to be found, also maximise the log likelihood function $ll(x|\alpha,\beta)$ which is easier to compute:

$$ll(x|\alpha,\beta) = -N \ln(2\pi)^{\frac{1}{2}} - N \ln(\beta) - \sum_{i=1}^{N} \ln(x_i) - \sum_{i=1}^{N} [(\ln(x_i)-\alpha)/\beta\sqrt{2}]^2$$

where the x represents the sample collectively.
The likelihood estimates are drawn from the equalities:

$$\frac{\partial ll}{\partial \hat{\alpha}} = 0 \quad \text{and} \quad \frac{\partial ll}{\partial \hat{\beta}^2} = 0$$

From the first equality: $\hat{\alpha} = \frac{1}{N} \sum_{i=1}^{N} \ln(x_i)$

From the second equality: $\hat{\beta}^2 = \frac{1}{N-1} \sum_{i=1}^{N} (\ln(x_i)-\alpha)^2$

Calculation of the Quantiles

The quantile x_p corresponding to the probability p and defined as prob $(x < x_p)=p$ can be calculated by:

$$x_p = \exp(U_p.\beta + \alpha) + x_o \qquad \text{with } x_o=0 \text{ in this case:}$$

U_p is the standard Normal variate corresponding to the probability p. In Abramowitz and Stegun (1964) one can find for $0.5<p<1$

$$U_p = t - \frac{C_o + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} + \sum(p)$$

Where $t = [\ln(1/(1-p)^2)]^{1/2}$

and $C_o = 2.515517$; $C_1 = 0.802853$; $C_2 = 0.010328$
$d_1 = 1.432788$; $d_2 = 0.189269$; $d_3 = 0.001308$

The error $\sum(p)$ remains lower than 4.5×10^{-4}
For $0<p<0.5$ or can calculate U_{1-p} and then $U_p = -U_{1-p}$

The calculation of U_p by this method has been widely used for the computation of the quantiles in this study.

The Confidence Interval

The bounds of the confidence interval of a quantile x_p are calculated with the general formula:

$$xp \pm U(1-\alpha/2).\ \sigma_{xp}$$

where $U(1-\alpha/2)$ is the standard normal variate for the level of confidence $1-\alpha$. In this report α=10% has been chosen so $U(1-\alpha/2) = 1.645$.

For both the methods of moments and maximum likelihood the bounds of the confidence interval can be worked out by the following procedure:

$$x_p \pm U(1-\alpha/2).\sigma_{xp} = e^{Z_p \pm U(1-\alpha/2).\sigma_{zp}}$$

where $Z_p = \ln(x_p)$ and $\sigma_{zp} = \frac{\beta}{\sqrt{N}} \cdot (1-U^2{}_{(p/2)})^{1/2}$

The Three Parameter Lognormal Distribution

The probability density function is expressed by the general formula of section 3.3.1.2.

The relation between x and the reduced variate is:

$y = \frac{x-x_o}{\alpha}$ and $F(x) = G(y)$ where $G(y)$ is the cumulative probability function of y.

Calculation of the Parameters by the Method of Moments

The parameters estimated by the method of moments can be worked out according to the following procedure:

$$\hat{\beta} = (2\ \ln(A))^{1/2}$$

$$\hat{\alpha} = \tfrac{1}{2}.\ln[(\hat{\sigma}_x^2/(A^2(A^2-1))]$$

$$x_o = \bar{x} - A\ e^{\alpha}$$

where $A^2 = (1 + C + (2C + C^2)^{1/2})^{1/3} + (1 + C - (2C + C^2)^{1/2})^{1/3} - 1$

and $C = \dfrac{\mu_3^2}{2(\hat{\sigma}_x)^6}$ and μ_3 is the third moment; $\mu_3 = E[(x-\bar{x})^3]$.

Calculation of the Parameters by the Method of Maximum Likelihood

As noted previously in the corresponding section for the 2 parameter lognormal distribution, it is easier to work with the log likelihood function:

$$LL(x|\alpha,\ \beta,\ x_o) = -N\ \ln(2\pi)^{1/2} - N\ \ln(\beta) - \sum_{i=1}^{N} \ln(x_i - x_o) - \tfrac{1}{2} \sum_{i=1}^{N} [(\ln(x_i - x_o) - \alpha)]/\beta$$

From $\dfrac{\partial ll}{\partial \hat{\alpha}} = 0$ we can deduce : $\hat{\alpha} = \dfrac{1}{N} \sum_{i=1}^{N} \ln(x_i - \hat{x}_o)$

From $\dfrac{\partial ll}{\partial \hat{\beta}^2} = 0$ it can be similarly shown : $\hat{\beta}^2 = \dfrac{1}{N} \sum_{i=1}^{N} [\ln(x_i - \hat{x}_o) - \alpha]$

$\hat{\alpha}$ and $\hat{\beta}$ are known once $\hat{x}_o$ is known.

$\hat{x}_o$ is solution of the equation $f(x_o) = 0$ where:

$$f(x_o) = \sum_{i=1}^{N} \frac{1}{x_i - x_o} \left[\frac{1}{N} \sum_{i=1}^{N} \ln^2(x_i - x_o) - \frac{1}{N^2} \left(\sum_{i=1}^{N} \ln(x_i - x_o)\right)^2 - \frac{1}{N} \sum_{i=1}^{N} \ln(x_i - x_o)\right]$$

$$+ \sum_{i=1}^{N} \ln(x_i - x_o)/(x_i - x_o)$$

The solution x_o to this equation is found using the iterative method of Newton where $x_o(n-1)$ is corrected at the n th iteration:

$$x_o(n) = x_o(n-1) - f(x_o(n-1))/f'(x_o(n-1))$$

A flow chart applying this method is proposed in Appendix 3.1.a.

Calculation of the Quantiles

The same formula applied previously for the two parameter lognormal distribution can be used here with $x_o \neq 0$.

The Confidence Interval

Method of Moments

The variance of the quantile x_p can be estimated using the Taylor's series expansion:

$$\mathrm{var}(x_p) = (\partial x_p/\partial \bar{x})^2 .\ \mathrm{var}\ (\bar{x}) + (\partial x_p/\partial \hat{\sigma}^2)^2 .\ \mathrm{var}\ (\hat{\sigma}^2) + (\partial x_p/\partial \hat{\beta}_3)^2 .\ \mathrm{var}\ (\hat{\beta}_3)$$

$$+ 2\ \partial x_p/\partial \bar{x}\ .\ \partial x_p/\partial \hat{\sigma}^2 .\ \mathrm{cov}(\bar{x}, \hat{\sigma}^2) + 2\ \partial x_p/\partial \bar{x}\ .\ \partial x_p/\partial \hat{\beta}_3\ .\mathrm{cov}(\bar{x}, \hat{\beta}_3)$$

$$+ 2\ \partial x_p/\partial \hat{\sigma}^2\ .\ \partial x_p/\partial \hat{\beta}_3\ .\ \mathrm{cov}(\hat{\sigma}^2, \hat{\beta}_3)$$

where: $\dfrac{\partial xp}{\partial \bar{x}} = 1$

$$\frac{\partial x_p}{\partial \hat{\sigma}^2} = \frac{1}{2\hat{\sigma}} \left(K_p - 3g \frac{\partial k_p}{\partial g}\right)$$

$$\frac{\partial x_p}{\partial \hat{\mu}_3} = \frac{1}{\hat{\sigma}^2} \cdot \frac{\partial k_p}{\partial g}$$

K_p is the frequency factor: $x_p = K_p . \sigma + \mu$

$$K_p = \frac{\exp(U_p . \beta - \beta^2/2) - 1}{(\exp(\beta^2) - 1)^{1/2}}$$

and:

$$\mathrm{Var}(\bar{x}) = \frac{\mu_2}{N}$$

$$\mathrm{var}(\hat{\sigma}^2) = \frac{1}{N}(\mu_4 - \mu_2^2)$$

$$\mathrm{Var}(\hat{\mu}_3) = \frac{1}{N}(\mu_6 - \mu_3^2 - 6\,\mu_4\,\mu_2 + 9\,\mu_2^3)$$

$$\mathrm{Cov}(\hat{\sigma}^2, \bar{x}) = \mu_3/N$$

$$\mathrm{Cov}(\hat{\mu}_3, \bar{x}) = \frac{1}{N}(\mu_4 - 3\mu_2^2)$$

$$\mathrm{Cov}(\hat{\sigma}^2, \hat{\mu}_3) = \frac{1}{N}(\mu_5 - 4\mu_3\,\mu_2)$$

μ_2, μ_3, μ_4, μ_5, and μ_6 being the second, third, fourth, fifth and sixth moments calculated upon the N values of the sample.

Method of Maximum Likelihood:

In this case variance(x_p) can also be estimated by a Taylor's expansion:

$$\text{var}\ (x_p) = (\delta x_p/\delta\hat{\alpha})^2.\text{var}\ (\hat{\alpha}) + (\delta x_p/\delta\hat{\beta})^2.\text{var}\ (\hat{\beta}^2) + (\delta x_p/\delta x_o)^2.\text{var}\ (\hat{x}_o)$$

$$+ 2\ \delta x_p/\delta\hat{\alpha}.\delta x_p/\delta\hat{\beta}^2.\text{cov}\ (\hat{\alpha},\ \hat{\beta}^2) + 2\ \delta x_p/\delta\hat{\alpha}.\delta x_p/\delta\hat{x}_o.\text{cov}\ (\hat{\alpha},\ \hat{x}_o)$$

$$+ 2\ \delta x_p/\delta\hat{\beta}^2.\delta x_p/\delta\hat{x}_o.\text{cov}\ (\hat{\beta}^2,\ \hat{x}_o)$$

with: $$\frac{\delta x_p}{\delta\hat{x}o} = 1$$

$$\frac{\delta x_p}{\delta\hat{\beta}^2} = \frac{u_p}{2\beta}\ .\ \exp(u_p.\beta + \alpha)$$

$$\frac{\delta x_p}{\delta\hat{\alpha}} = \exp(u_p.\beta + \alpha)$$

and: $$\text{var}\ (\hat{\alpha}) = \frac{\hat{\beta}^2}{ND}\ [\ (\hat{\beta}^2 + 1)/2\hat{\beta}^2\ .\ \exp(2(\hat{\beta}^2 - \hat{\alpha})) - \exp(\hat{\beta}^2 - 2\hat{\alpha})]$$

$$\text{var}\ (\hat{\beta}^2) = \frac{\hat{\beta}^2}{ND}\ [(\hat{\beta}^2 + 1)\ .\ \exp(2(\hat{\beta}^2 - \hat{\alpha})) - \exp(\hat{\beta}^2 - 2\hat{\alpha})]$$

$$\text{var}(\hat{x}_o) = \frac{1}{2ND}$$

$$\text{cov}\ (\hat{\alpha},\ \hat{\beta}^2) = \frac{-\hat{\beta}^2}{ND}\quad \exp(\hat{\beta}^2 - 2\hat{\alpha})$$

$$\text{cov}\ (\hat{\alpha},\ \hat{x}_o) = \frac{-1}{2ND}\quad \exp(\hat{\beta}^2/2 - \hat{\alpha})$$

$$\text{cov}\ (\hat{\beta}^2,\ \hat{x}_p) = \frac{\hat{\beta}^2}{ND}\ \exp(\hat{\beta}^2/2 - \hat{\alpha})$$

$$D = \frac{\hat{\beta}^2 + 1}{2\hat{\beta}^2} \cdot \exp(2(\hat{\beta}^2 - \hat{\alpha})) - \frac{2\hat{\beta}^2 + 1}{2\hat{\beta}^2} \cdot \exp(\hat{\beta}^2 - 2\hat{\alpha})$$

Then for both methods of moments and maximum likelihood, the bounds of the confidence interval are calculated by:

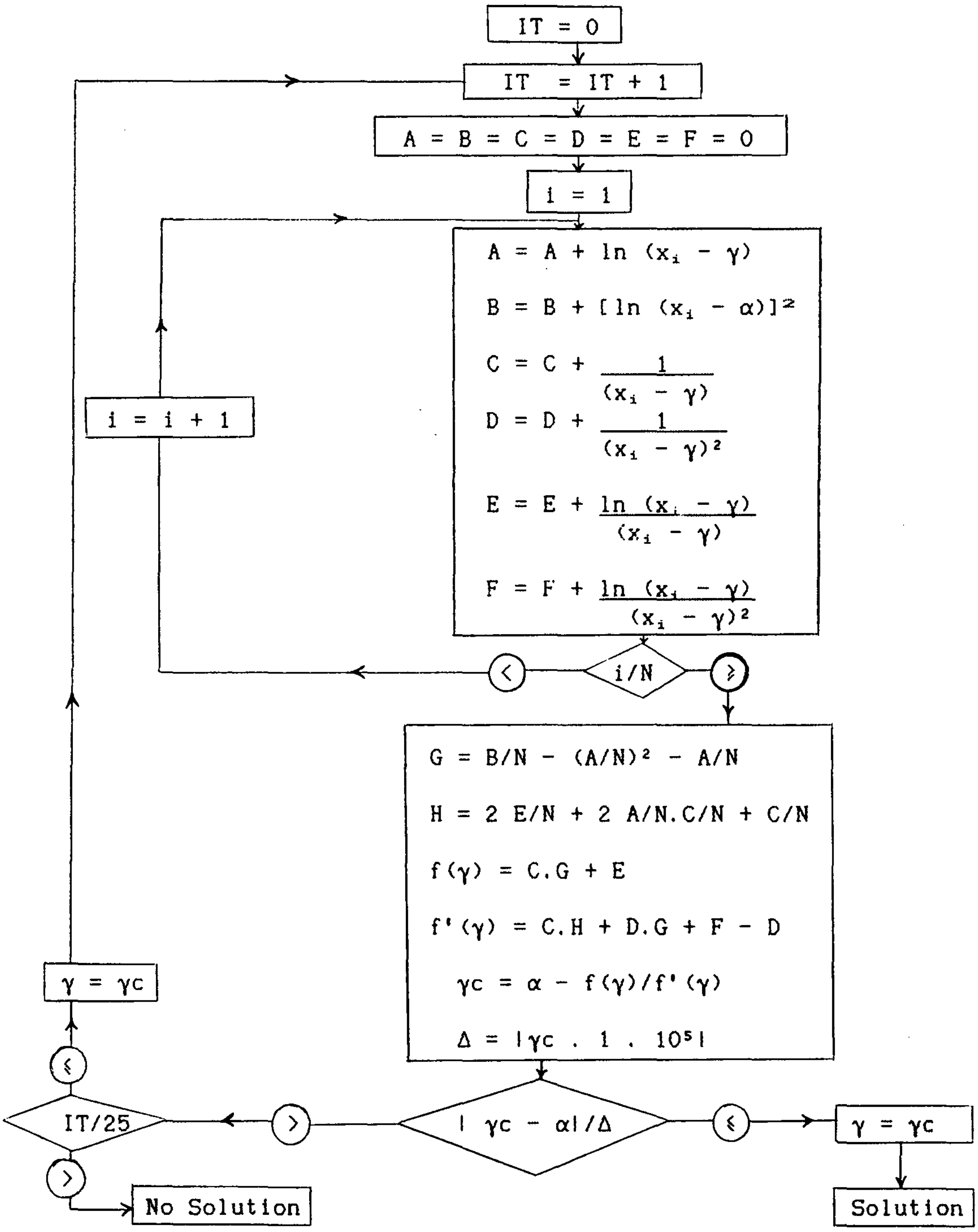
$$x_p \pm U(1-\alpha/2)\ .\ [\text{Var}\ (x_p)]^{1/2}$$

APPENDIX 3.1.a

Flow chart to calculate the location parameter x_o of the three parameter lognormal distribution (method of maximum likelihood). After Masson (1985).

$xm = \text{MINIMUM}\ (x_1,\ x_2,\ x_3,\ \ldots\ldots x_n)$

$x_o = \gamma = 0.8\ xm$



APPENDIX 3.2. The general extreme value distribution.

The Gumbel or EV1 Distribution

The probability density function of the Gumbel distribution is:

$$f(x) = \frac{1}{\alpha} \exp\left[-(x - u)/\alpha - e^{-(x-u)/\alpha}\right]$$

and its cumulative distribution function is easy to compute:

$$F(x) = \exp\left(-e^{-(x-u)/\alpha}\right)$$

The k referred to above being equal to zero, two parameters only appear in these expressions.

u is the location parameter.
α is the scale parameter.

The standardised or reduced variate y is related to x by the relation:

$$y = (x - u)/\alpha = -\ln(-\ln(F(x)))$$

with $g(y) = \exp(-y-e^{-y})$

and $G(y) = \exp(-e^{-y}) = F(x)$.

The plotting position formula used is the Gringorten formula which is also used for the EV2 distribution:

$$F_i = (i-0.44) \;/\; (N + 0.12) \quad \text{where } i = \text{rank}.$$

Calculation of the Parameters by the Method of Moments

The relations between the two first moments of the sample and the parameters are:

$$\hat{\alpha} = 0.78\ \hat{\sigma}$$

$$\hat{u} = \bar{x} - 0.577\ \hat{\alpha} = \bar{x} - 0.45\ \hat{\sigma}$$

Calculation of the Parameters by the Method of Maximum Likelihood

The likelihood function as defined previously is $L(x|u, \alpha)$ where x represents the sample collectively :

$$L(x|\ u,\ \alpha) = \prod_{i=1}^{N} f(x_i|u,\ \alpha)$$

$$= \frac{1}{\alpha^N} \exp\left[-\sum_{i=1}^{N}(x_i - u)/\alpha - \sum_{i=1}^{N} e^{-(x_i-u)/\alpha}\right]$$

The maximum likelihood estimates (the values of u and α which maximise the above quantity) also maximise the log likelihood (which is easier to work with) defined as:

$$LL(x|u,\ \alpha) = -N.\ln(\alpha) - \sum_{i=1}^{N} y_i - \sum_{i=1}^{N} e^{-y_i}$$

The likelihood estimates are computed by an iterative process where the estimates u_i and α_i are progressively revised by two converging equations:

$$u_{i+1} = u_i + \delta u_i \quad \text{and} \quad \alpha_{i+1} = \alpha_i + \delta\alpha_i$$

The initial values u_0 and α_0 are the estimates calculated by the method of moments.

In Appendix 3.2.a, a flow chart displays the iterative method of Newton used to calculate the estimates. To understand the flow chart it is necessary to transfer: xo = u and S = α. The convergence limit Σ has been set to 0.0001.

Calculation of the Quantiles

The value of a quantile x_p is easily obtained from the definition of $F(x)$:

$$x_p = -\alpha .\ \ln(-\ln(F(x_p))) + u$$

The Confidence Interval

As defined previously the bounds of the confidence interval of a quantile x_p are calculated with the formula:

$$x_p \pm U(1-\alpha/2).\ \sigma_{xp}$$

the problem being to calculate σ_{xp}, the standard error of the quantile x_p.

Method of Moments

Lowery and Nash (1970) proposed:

$$\sigma_{xp} = \frac{\hat{\sigma}}{\sqrt{N}} \quad [1-1.1396(0.45 + 0.7797\ y_p) + 1.1(0.45 + 0.7797\ y_p)^2]^{1/2}$$

Method of Maximum likelihood:

In Masson (report LHM 06/1983, 1983) or NERC (1975, p.103) one can find:

$$\sigma_{xp} = \frac{\alpha}{\sqrt{N}} \; [0.6079\, y_p^2 + 0.514 y_p + 1.1086]$$

<u>The Fréchet or EV2 Distribution</u>

This distribution also known as the log-Gumbel distribution is defined by its probability density function:

$$f(x) = \frac{1}{\alpha}\, (1-k(x-u)/\alpha)^{1/k-1} \,.\, \exp(-[1-k(x-u)/\alpha]^{1/k})$$

or by its cumulative density function;

$$F(x) = \exp(-[1-k(x-u)/\alpha]^{1/k})$$

with $k<0$, $\alpha>0$ and $u + \frac{\alpha}{k} \leqslant x \leqslant \infty$

The reduced variate y is:

$$y = 1 - \frac{x-u}{\alpha}\, k = \exp[(k \ln(-\ln(F(x)))] \text{ with } 0 \leqslant y \leqslant \infty$$

The probability and cumulative density functions are defined as:

$$g(y) = \frac{-y^{1/k-1}}{k} \,.\, \exp(-y^{1/k})$$

$$G(y) = \exp(-y^{1/k}) = F(x)$$

Calculation of the Parameters by the Method of Moments

The calculation of the parameters is carried out through several steps.

The first parameter to work out is k. The skewness g is a dimensionless quantity and depends only on the shape parameter k:

$$g = \mu_3 / (\mu_2)^{3/2}$$

with: $\mu_2 = \mathrm{var}(y) = \Gamma(1 + 2\ k) - \Gamma^2(1 + k)$

$$\mu_3 = E[y - E(y)]^3 = \Gamma(1 + 3\ k) - 3\Gamma(1 + 2\ k).\Gamma(1 + k) + 2\Gamma^3(1 + k)$$

The function $\Gamma(x)$ (gamma) is not easy to compute but the function $\ln[(\Gamma(x)]$ can be approximated (Abramowitz and Stegun, 1964) by the expression:

$$\ln[\Gamma(x)] = (x - 1/2).\ \ln(x) - x + ½ \ln(2\pi) + \frac{1}{12x} - \frac{1}{360x^3} + \frac{1}{1260x^5} - \frac{1}{1680x^7} + \ldots$$

and $\Gamma(x) = \exp[\ln(\Gamma(x))]$

This relation is more accurate as x is high hence we can also use:

$$\ln[\Gamma(x)] = \ln(\Gamma(x + n)) - \ln[x(x + 1)(x + 2)\ldots(x + n - 1)]$$

If $18 < x < 10^{10}$ then only the first equation is used.

If $x < 18$ then an integer n is added such that $(x + n)$ is higher than 18 and the two equations are used.

Then the method of dichotomy is applied to find the value of k which is the solution of the equation:

$$g - \mu_3/(\mu_2)^{3/2} = 0$$

This method provides accurate values of k if $g > 1.7$.

Once k is known, the estimates $\hat{\alpha}$ and $\hat{u}$ are easily calculated:

$$\hat{\alpha} = -\hat{k}.((\hat{\sigma}_x)^2/\text{var}(y))^{1/2} = -\hat{k} \, . \, \hat{B}$$

$$\hat{u} = \hat{A} + \hat{B} \quad \text{with } \hat{A} = \bar{x} - \hat{B}.E(y) \text{ and } E(y) = \Gamma(1 + k)$$

Calculation of the Parameters by the Method of Maximum Likelihood

The principle is the same than for the EV1 distribution. The maximum likelihood solution (the set of estimated parameters $\hat{\alpha}$, $\hat{k}$ and $\hat{u}$) is sought to maximise the log likelihood function $LL(x|u, \alpha, k)$ as Jenkinson (1969) reported:

$$LL(x|u, \alpha, k) = -N\ln(\alpha) - (1-k).\sum_{i=1}^{N} w_i - \sum_{i=1}^{N} e^{-w_i}$$

where $w_i = -\dfrac{1}{k} \ln(1 - k(x_i - u)/\alpha)$

The estimates $\hat{\alpha}$, $\hat{u}$ and $\hat{k}$ are worked out using an iterative process:

$$u_{j+1} = u_j + \delta\mu_j$$
$$\alpha_{j+1} = \alpha_j + \delta\alpha_j$$
$$k_{j+1} = k_j + \delta k_j$$

when δu_j, $\delta\alpha_j$ and δk_j are sufficiently small, the iterations are stopped.

The initial values u_o, α_o and k_o are the parameters determined by the method of moments.

The values of δ can be computed using the following formulas:

$$\delta u_j = -\frac{\alpha_j}{N}\,[b\ Q_j + h\ (P_j + Q_j)/k_j + f\ (R_j - (P_j + Q_j)/k_j)/k_j]$$

$$\delta\alpha_j = -\frac{\alpha_j}{N}\,[h\ Q_j + a\ (P_j + Q_j)/k_j + g\ (R_j - (P_j + Q_j)/k_j)/k_j]$$

$$\delta k_j = \frac{-1}{N}\,[f\ Q_j + g\ (P_j + Q_j)/k_j + c\ (R_j - (P_j + Q_j)/k_j)/k_j]$$

where:

$$P_j = N - \sum_{i=1}^{N} e^{-w_i}$$

$$Q_j = \sum_{i=1}^{N} e^{w_i + k_j . w_i} - (1 - k_j).\ \sum_{i=1}^{N} e^{k_j . w_i}$$

$$R_j = N - \sum_{i=1}^{N} w_i + \sum_{i=1}^{N} w_i\ e^{-w_i}$$

The values of the coefficients a, b, c, f, g, h can be extracted from the variance - covariance matrix of the estimators ($\hat{u}$, $\hat{\alpha}$, $\hat{k}$) and depend on the value of k. The values of those coefficients are provided by the Flood Studies Report (NERC, 1975) down to k =-0.4 (Jenkinson, 1969). In this particular case, some values of k were lower than -0.4 so a computing program had to be set up to work out those coefficients to a value of k down to -1. The values of the coefficients corresponding to intermediate

values of k have been worked out by linear interpolation.
Table 3.2.1 displays the values of the coefficients.

Table 3.2.1. Coefficients involved in the computation of the parameters of the Fréchet distribution (method of maximum likelihood).

k	a	b	c	f	g	h
0	0.65	1.25	0.48	0.26	0.15	0.34
-0.1	0.72	1.27	0.55	0.26	0.10	0.46
-0.2	0.81	1.28	0.64	0.26	0.04	0.57
-0.3	0.92	1.29	0.73	0.26	-0.03	0.69
-0.4	1.05	1.29	0.84	0.26	-0.09	0.80
-0.5	1.19	1.29	0.94	0.25	-0.17	0.91
-0.6	1.37	1.29	1.05	0.23	-0.25	1.02
-0.7	1.56	1.28	1.16	0.21	-0.34	1.13
-0.8	1.78	1.28	1.29	0.18	-0.44	1.24
-0.9	2.02	1.27	1.41	0.15	-0.54	1.34
-1.0	2.28	1.26	1.55	0.12	-0.66	1.45

Calculation of the Quantiles

The formula giving the quantile x_p corresponding to the probability p is drawn from the cumulative density function, hence:

$$x_p = u + \alpha/k.[1-\exp\{k.\ln(-\ln(F(x_p)))\}]$$

Where $F(x_p) = P$.

The Confidence Interval

The method to compute the standard error σ_{xp} has been found in the literature (NERC,1975) only for the maximum likelihood estimation:

$$\sigma_{x_p} = \frac{\alpha W}{\sqrt{N}} \left[a + b/w^2 + c/w^2.(dw/dk)^2 + 2\,h/w + 2\,(g/w + 2f/w^2).dw/dk \right]^{1/2}$$

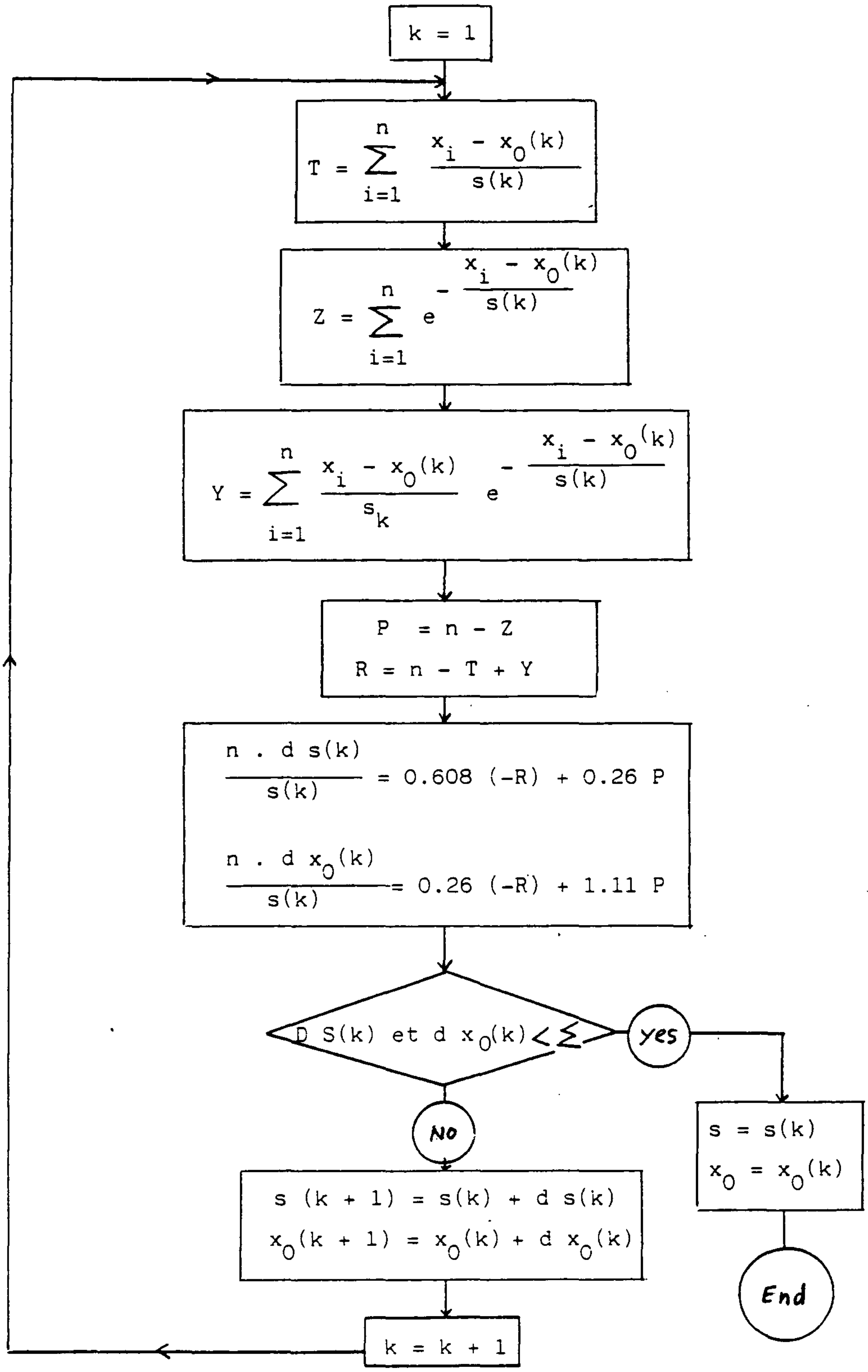
where $w = \dfrac{1 - e^{-ky}}{k}$; $\dfrac{dw}{dk} = (ye^{-ky} - w)/k$

and $y = \dfrac{x_p - u}{\alpha}$ (reduced variate for the Gumbel Distribution).

Despite the fact that this formula has been derived in a standard way, it is not satisfactory (pronounced funnel shape) when the estimated quantile approaches the upper bound of the variate values.

APPENDIX 3.2.a

Iterative method of Newton to compute the parameters of the Gumbel distribution by the method of maximum likelihood. After Masson (report LHM 13/1983, 1983).



APPENDIX 3.3. The Pearson Type 3 and gamma distributions.

Pearson Type 3 Distribution

Calculation of the Parameters by the Method of Moments.

Three parameters are to be estimated so three easy relations are to be used:

$$\hat{\gamma} = 4 / \hat{g}^2$$

$$\hat{\beta} = \hat{g}\ \hat{\sigma}_x / 2$$

$$\hat{x}_o = \bar{x} - \hat{\beta}.\hat{\gamma}$$

Calculation of the Parameters by the Method of Maximum Likelihood

The function to maximise is the log likelihood function . As presented for the previous distributions, the maximum likelihood estimates must satisfy:

$$\partial LL/\partial \hat{x}_o = 0,\ \partial LL/\partial \hat{\beta} = 0 \text{ and } \partial LL/\partial \hat{\gamma} = 0$$

From the first two equations it can be drawn:

$$\gamma = \frac{\sum_{i=1}^{N} (x_i - \hat{x}_o)^{-1}}{\sum_{i=1}^{N} (x_i - \hat{x}_o)^{-1} - N^2 / \sum_{i=1}^{N} (x_i - \hat{x}_o)}$$

$$\hat{\beta} = \frac{1}{N} \sum (x_i - \hat{x}_o) - N / \sum_{i=1}^{N} (x_i - \hat{x}_o)^{-1}$$

Infortunately x_o must be calculated first and its computation is not straightforward.

The previous equation $\frac{\partial LL}{\partial \hat{\gamma}} = 0$ can be changed into the equivalent equation:

$$G(x_o) = \frac{1}{N} \sum_{i=1}^{N} (x_i - x_o) - \ln(\beta) - \emptyset'(\gamma) = 0$$

where $\emptyset'(\gamma) = \frac{\partial \ln(\Gamma(\gamma))}{\partial \gamma}$ = digamma or PSI function

and $LX = \frac{1}{N} \sum_{i=1}^{N} (x_i - x_o)$

The method to calculate $\emptyset'(\gamma)$ is given in the section referring to the gamma distribution .
The value of $\hat{x}_o$ annulling $G(x_o)$ is worked out by the method of dichotomy whose flow chart is presented in appendix 3.3.a. The initial lower value to start the computation with is the lowest piece of EMC data from the sample (called $x_o(1)$).

Calculation of the quantiles

The quantiles can be computed using the same formulas as those presented for the gamma distribution.

__The Confidence Interval__

Method of Moments:

The standard error of the quantile x_p is (after Masson, report LHM 06/1983, 1983):

$$\sigma_{xp} = \frac{\hat{\sigma}_x}{\sqrt{N}} \{1 + Kp.g + Kp^2/2.(1 + 3g^2/4) + 3.Kp.\partial Kp/\partial g.[g + g^3/4] + 3(\partial Kp/\partial g)^2.(2 + 3g^2 + 5g^4/8)\}$$

where Kp (frequency factor) can be calculated by the formula provided in the section for the gamma distribution and:

$$\frac{\partial kp}{\partial g} = (U_p^2 - 1)/6 + 4(U_p^3 - 6g\ U_p)/6^3 - 3(U_p^2 - 1)\ g^2/6^3 + 4U_p\ g^3/6^4 - 10\ g^4/6^6$$

Method of maximum likelihood:

σ_{xp}^2 can be calculated using the formula for a three parameter distribution given in the section about the gamma distribution:

$$\mathrm{var}(\gamma) = \frac{2N^2}{D\ \beta^4\ (\gamma-2)}$$

$$\mathrm{var}(\beta) = \frac{N^2}{D\beta^2}\left[\emptyset''(\gamma)/(\gamma-2) - 1/(\gamma-1)^2\right]$$

$$\mathrm{var}(x_o) = \frac{N^2(\gamma.\emptyset''(\gamma) - 1)}{D\ \beta^2}$$

$$\mathrm{cov}(\gamma,\ \beta) = \frac{N^2}{D\beta^3}\left[1/(\gamma-1) - 1/(\gamma-2)\right]$$

$$\mathrm{cov}(\gamma,\ x_o) = \frac{N^2}{D\beta^3}\left(1 - \gamma/(\gamma-1)\right)$$

$$\mathrm{cov}(\beta,\ x_o) = \frac{N^2}{D\beta^2}\left(1/(\gamma-1) - \phi''(\gamma) \right)$$

$$\text{with } D = \frac{N^3}{\beta^4\ (\gamma-2)}\left[2\ \phi''(\gamma) - (2\gamma-3)/(\gamma-1)^2\right]$$

and $\phi''(\gamma)$ is the trigamma function presented in the section for the gamma distribution. $\frac{\partial x_p}{\partial \gamma}$, $\frac{\partial x_p}{\partial \beta}$ and $\frac{\partial x_p}{\partial x_o}$ are calculated by the formulas given in that section.

The Gamma Distribution

This distribution can be regarded as a Pearson Type 3 distribution with a location parameter x_o equal to zero. Hence its probability density function is:

$$F(x) = \frac{x^{\gamma-1}\ .\ e^{-x/\beta}}{\beta^{\gamma}\ \Gamma(\gamma)} \qquad \text{with } \gamma > 0$$

The cumulative probability function cannot be defined by a simple expression :

$$F(x) = \int_0^x f(x)\ .\ dx$$

When γ is large the distribution tends to be a normal distribution. The reduced variate y is related to x by:

$$g(y) = \frac{y^{\gamma-1}\ .\ e^{-y}}{\Gamma(\gamma)} \quad \text{and} \quad G(y) = \int_0^y g(y).dy$$

G(y) depends only on the parameter γ and therefore G(y) can be tabulated for various positive values of γ.

Calculation of the Parameters by the Method of Moments.

The estimated parameters are worked out through the straightforward equations:

$$\hat{\gamma} = \bar{x}^2/(\hat{\sigma}_x)^2$$

$$\hat{\beta} = (\hat{\sigma}_x)^2/\bar{x}$$

Calculation of the Parameters by the Method of Maximum Likelihood.

The values of β and γ that maximise the log likelihood function $ll(x|\beta, \gamma)$ must be found. The maximum likelihood estimates must satisfy:

$$\frac{\partial ll}{\partial \hat{\beta}} = 0 \quad \text{and} \quad \frac{\partial ll}{\partial \hat{\gamma}} = 0$$

where $ll(x|\beta, \gamma) = -N\gamma \ln(\beta) - N \ln(\Gamma(\gamma)) - \sum_{i=1}^{N} x_i/\beta + (\gamma-1) \sum_{i=1}^{N} \ln(x_i)$

From the expression $\frac{\partial ll}{\partial \hat{\gamma}} = 0$ one can end up with the equivalent quantity:

$$\ln(\bar{x}/\gamma) + \frac{d\ln(\Gamma(\gamma))}{d\gamma} - \frac{1}{N} \sum_{i=1}^{N} \ln(x_i) = 0$$

Let $\frac{d\ln(\Gamma(\gamma))}{d\gamma} = \emptyset'(\gamma)$ = digamma or psi function.

Let $G(\gamma) = \ln\left(\bar{x}/\gamma\right) + \emptyset'(\gamma) - \frac{1}{N} \sum_{i=1}^{N} \ln(x_i)$

The value of $\hat{\gamma}$ that annuls $G(\gamma)$ can be worked out using either the method of dichotomy or the iterative method of Newton. The principle of the latter is to get directly the value of γ after n + 1 iterations:

$$\gamma_{n+1} = \gamma_n - G(\gamma_n) \ / \ G'(\gamma_n)$$

where $G'(\gamma) = \dfrac{\partial G(\gamma)}{\partial\gamma} = \dfrac{1}{\gamma} - \emptyset''(\gamma)$

$\emptyset''(\gamma)$ = tri function.

γ_o is the value of γ calculated by the method of moments. The flow chart to compute $\emptyset''(\gamma)$ is in Appendix 3.3.b whereas the one to compute $\emptyset''(\gamma)$ is provided in Appendix 3.3.c.

Once $\hat{\gamma}$ is known, it is easy to derive $\hat{\beta}$ from the expression $\dfrac{\partial LL}{\partial\hat{\beta}} = 0$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\gamma}}$$

Calculations of the Quantiles

The quantile x_p corresponding to the cumulative probability p can be calculated by different ways:

- x_p can be calculated using the χ^2 tables:

  $x_p = \chi^2(p, 2\gamma) \ . \ \beta/2 + x_o$ and 2γ is the degree of freedom;

- one can use the Harter's tables which provide the frequency factor Kp:

  $x_p = Kp.\hat{\sigma}_x + \bar{x}$

- In this study the Wilson-Hilferty's transformation has been used. This transformation (Kendall and Stuart, Vol. 1, P.401, 4th edition, 1977) allows a χ^2 variable to be expressed as a standard normal variate (Up):

$$x_p = \gamma \;.\; \beta \;.\; [1 - 1/9\gamma + Up.(1/9\gamma)^{1/2}]^3 + x_o$$

It must be remembered that $x_o = 0$ for the gamma distribution.

<u>**The Confidence Interval**</u>

Method of moments:

The bounds of the confidence interval are calculated by the formula:

$$x_p \pm U(1-\alpha/2) \;.\; \sigma_{xp}$$

where $\sigma_{xp} = \dfrac{\hat{\sigma}_x}{\sqrt{N}} \;.\; [1 + Kp.g + Kp^2/2.(1 + 3g^2/4)]^{1/2}$

$$Kp \text{ (frequency factor)} = Up + (Up^2 - 1).g/6 + (Up^3 - 6Up).(g/6)^2/3$$
$$- (Up^2 - 1).(g/6)^3 + Up.(g/6)^4 - (g/6)^5/3$$

g is the skewness of the sample.

Method of maximum likelihood:

For a three parameter distribution the sampling variance of the quantile x_p is expressed by:

$$\sigma_{xp}^2 = (\partial x_p/\partial\gamma)^2.\mathrm{var}\ (\gamma) + (\partial x_p/\partial\beta)^2.\mathrm{var}\ (\beta) + (\partial x_p/\partial x_o)^2\ \mathrm{var}\ (x_o)$$
$$+ 2\ \partial x_p/\partial\gamma.\partial x_p/\partial\beta.\mathrm{cov}\ (\gamma,\ \beta) + 2\ \partial x_p/\partial\gamma.\partial x_p/\partial x_o.\mathrm{cov}\ (\gamma,\ x_o)$$
$$+ 2\ \partial x_p/\partial\beta.\partial x_p/\partial x_o.\mathrm{cov}\ (\beta,\ x_o)$$

If we drop out the terms involving the parameter x_o we end up with a valid formula for the gamma distribution:

$$\sigma^2_{xp} = (\partial x_p/\partial\gamma)^2.\text{var}\ (\gamma) + (\partial x_p/\partial\beta)^2.\text{var}\ (\beta) + 2\ \partial x_p/\partial\gamma.\partial x_p/\partial\beta.\text{cov}\ (\beta,\ \gamma)$$

where:

$$\frac{\partial x_p}{\partial\gamma} = 3\beta\ [\ \gamma^{1/3} - 1/9\gamma^{2/3} + Up/3\gamma^{1/6}\ ]^2\ .\ [\ 1/3\gamma^{2/3} + 2/27\gamma^{5/3} - Up/18\gamma^{7/6}\ ]$$

$$\frac{\partial x_p}{\partial\beta} = [\ \gamma^{1/3} - 1/9\gamma^{2/3} + Up/3\gamma^{1/6}\ ]^3$$

$$\frac{\partial x_p}{\partial x_o} = 1$$

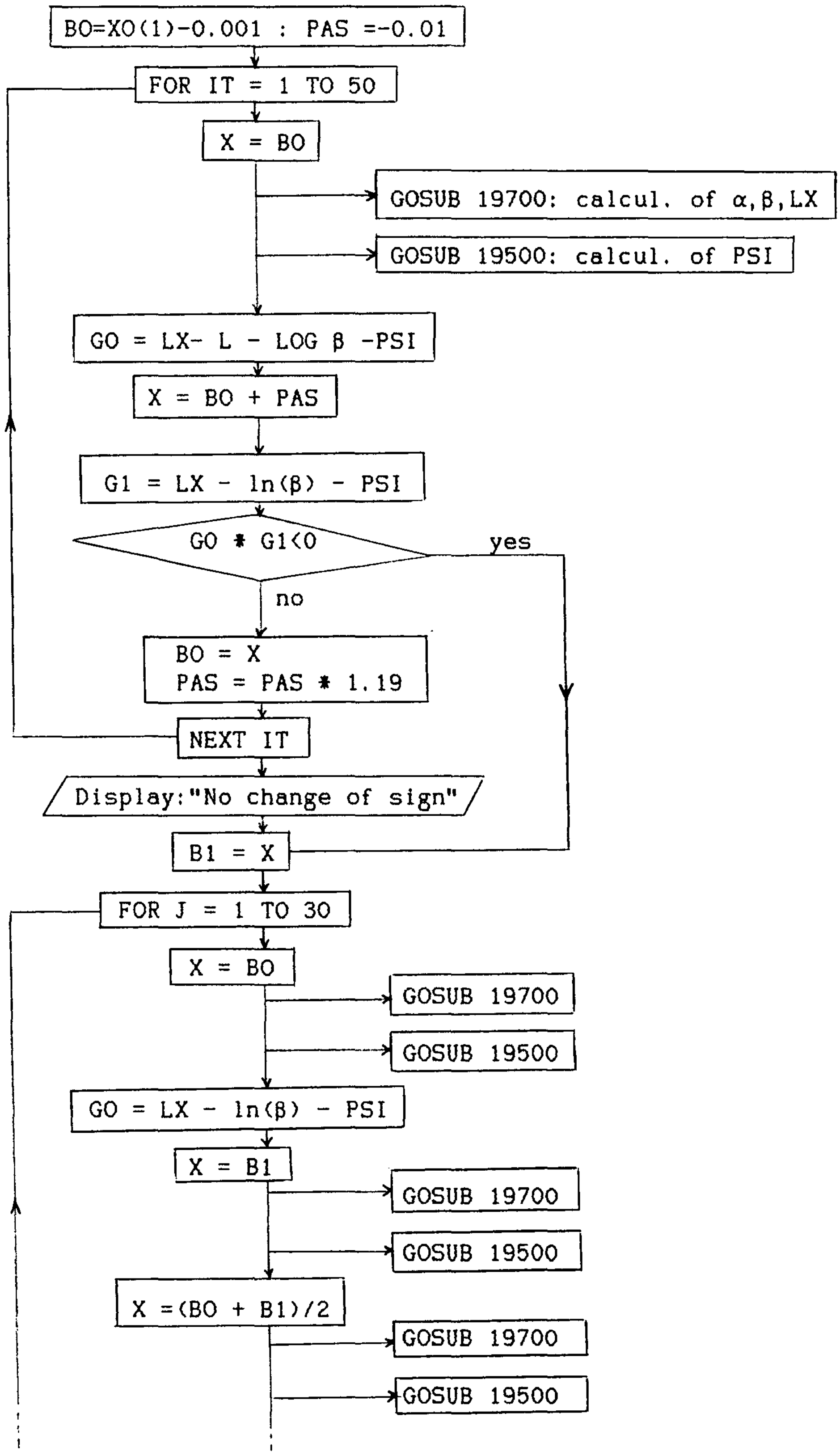
$$\text{var}\ (\gamma) = \frac{\gamma}{N\ (\gamma\ \emptyset''(\gamma) - 1)}$$

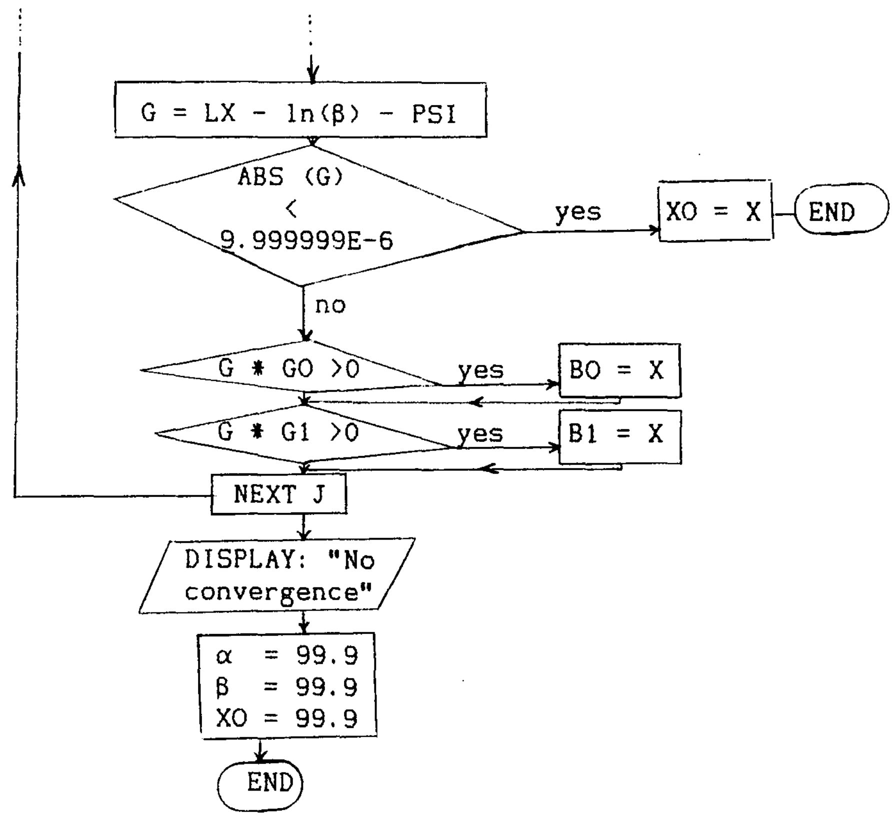
$$\text{var}\ (\beta) = \frac{\emptyset''(\gamma)\ \beta^2}{N\ (\gamma\ \emptyset''(\gamma) - 1)}$$

$$\text{cov}\ (\gamma,\ \beta) = -\frac{\beta}{N\ (\gamma\ \emptyset''(\gamma) - 1)}$$

APPENDIX 3.3.a

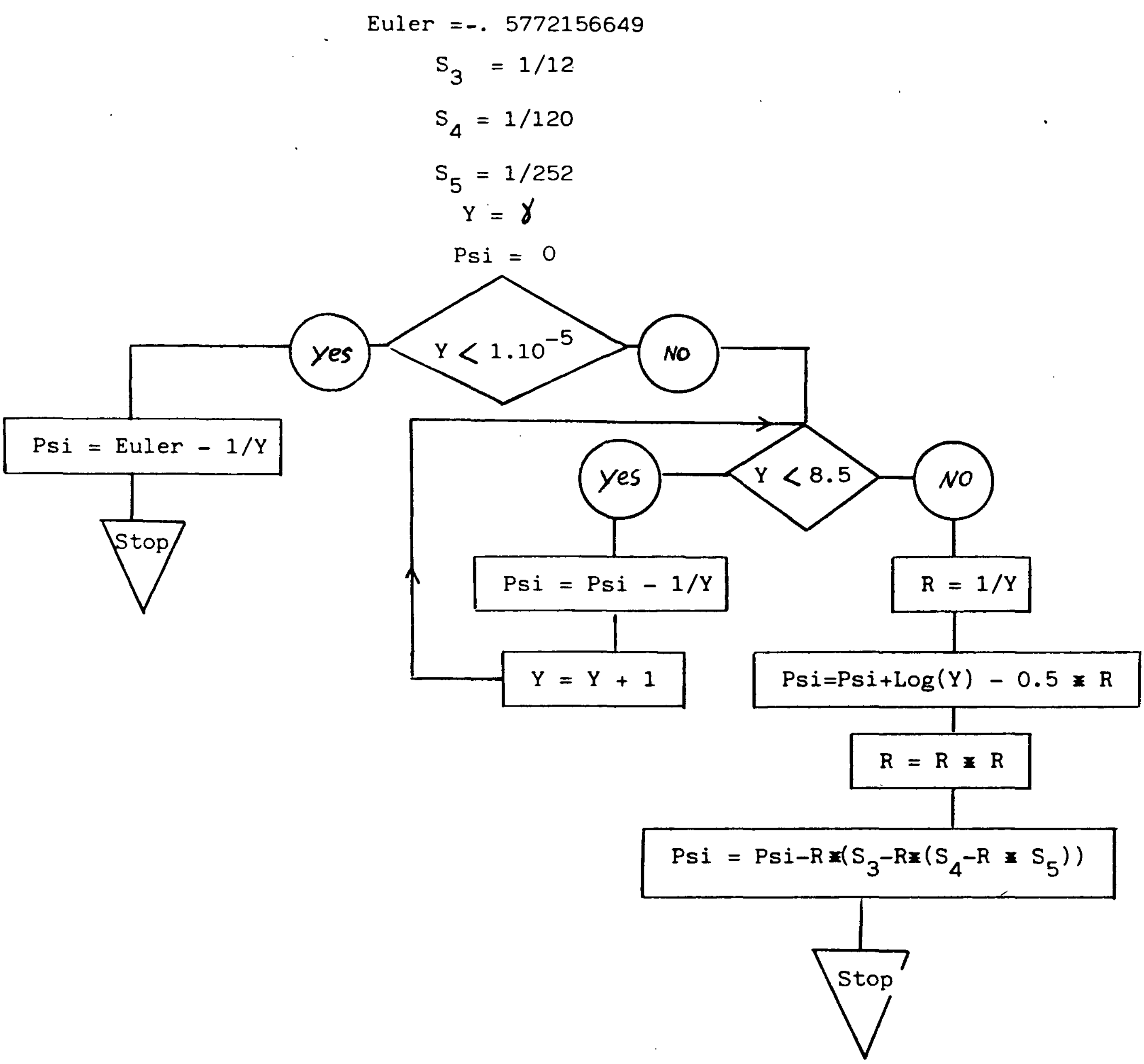
Flow chart showing the computing process of x_o (method of maximum likelihood for a Pearson Type 3 distribution).




G = LX - ln(β) - PSI
ABS (G)
<
9.999999E-6
yes
XO = X
END
no
G * GO >0
yes
BO = X
G * G1 >0
yes
B1 = X
NEXT J
DISPLAY: "No convergence"
α = 99.9
β = 99.9
XO = 99.9
END

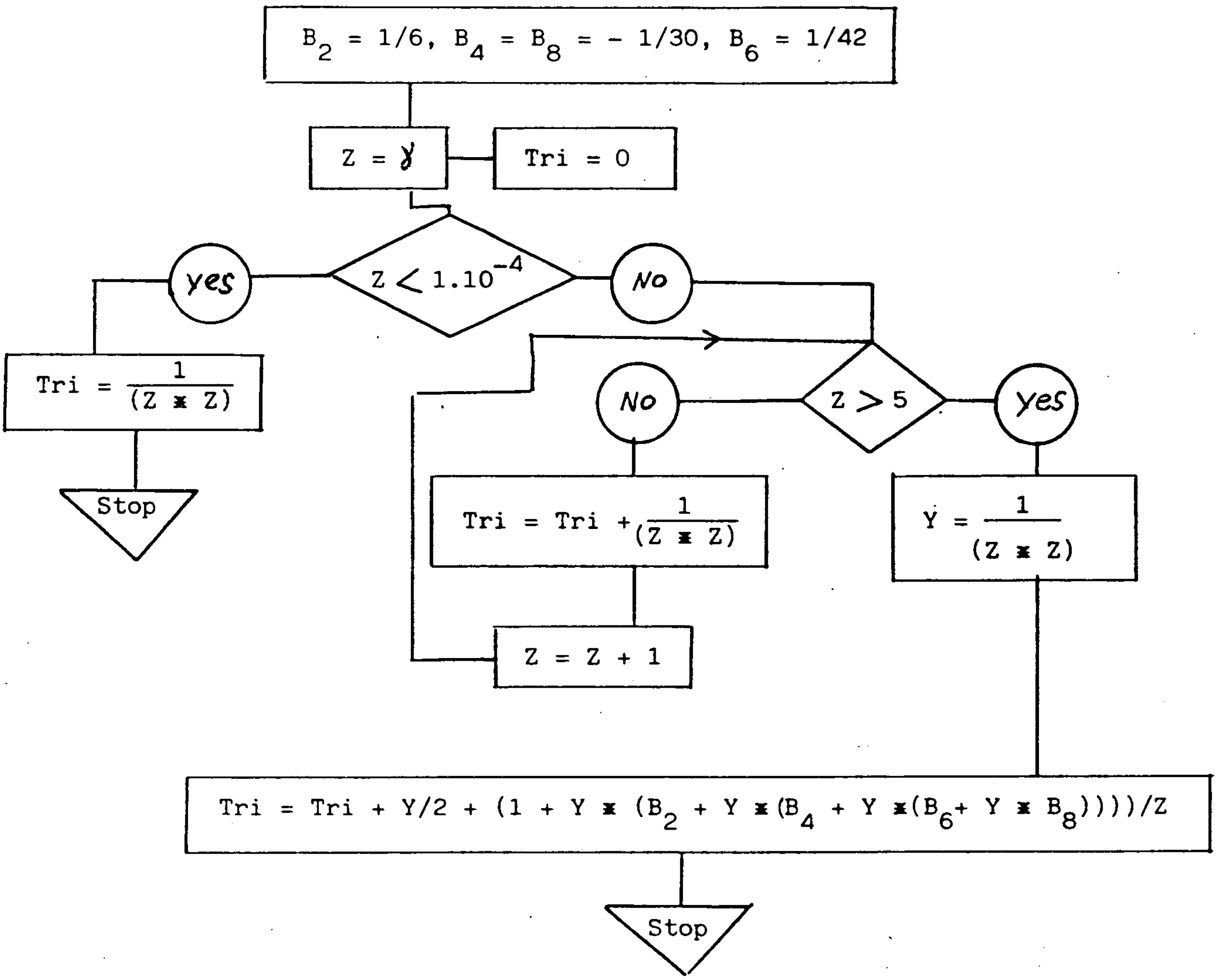
APPENDIX 3.3.b

Flow chart showing the method of computing Ø'(γ) (Method of maximum likelihood for the gamma distribution). After Masson (1982).



APPENDIX 3.3.c

Flow chart showing the method of computing Ø"(γ) (Method of maximum likelihood for the gamma distribution). After Masson (1982).



APPENDIX 4.1

Samples (for all pollution parameters and for the four French catchments) of ranked EMCs used to test the goodness of fit of the statistical distributions.

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF COD (mg/l) CATCHMENT : MAUREPAS
SIZE OF SAMPLE= 126 NUMBER OF EVENTS= 174

*	18	0.005	19	0.013	21	0.021	25	0.029	*
*	27	0.036	28	0.044	33	0.052	34	0.060	*
*	34	0.068	34	0.076	35	0.084	35	0.092	*
*	36	0.100	36	0.108	37	0.116	38	0.124	*
*	39	0.132	39	0.139	40	0.147	40	0.155	*
*	40	0.163	41	0.171	41	0.179	41	0.187	*
*	42	0.195	43	0.203	44	0.211	44	0.219	*
*	44	0.227	44	0.235	45	0.242	46	0.250	*
*	46	0.258	49	0.266	51	0.274	51	0.282	*
*	52	0.290	52	0.298	54	0.306	55	0.314	*
*	55	0.322	58	0.330	58	0.338	59	0.345	*
*	61	0.353	.61	0.361	61	0.369	63	0.377	*
*	65	0.385	65	0.393	66	0.401	68	0.409	*
*	68	0.417	69	0.425	69	0.433	71	0.441	*
*	73	0.448	74	0.456	75	0.464	76	0.472	*
*	76	0.480	77	0.488	77	0.496	79	0.504	*
*	80	0.512	81	0.520	83	0.528	83	0.536	*
*	85	0.544	87	0.552	87	0.559	89	0.567	*
*	89	0.575	90	0.583	90	0.591	90	0.599	*
*	92	0.607	92	0.615	95	0.623	96	0.631	*
*	97	0.639	97	0.647	97	0.655	102	0.662	*
*	104	0.670	105	0.678	105	0.686	106	0.694	*
*	106	0.702	108	0.710	109	0.718	114	0.726	*
*	117	0.734	119	0.742	124	0.750	124	0.758	*
*	125	0.765	126	0.773	128	0.781	129	0.789	*
*	130	0.797	130	0.805	132	0.813	133	0.821	*
*	134	0.829	137	0.837	144	0.845	152	0.853	*
*	162	0.861	164	0.868	168	0.876	171	0.884	*
*	173	0.892	176	0.900	187	0.908	194	0.916	*
*	197	0.924	205	0.932	217	0.940	223	0.948	*
*	237	0.956	240	0.964	294	0.971	346	0.979	*
*	442	0.987	590	0.995					*

* * STATISTICAL PARAMETERS OF THE SAMPLE *

*

MEAN= 97.82539

STANDARD DEVIATION= 78.83456

SKEWNESS= 3.067046

COEFFICIENT OF VARIATION= .8058701

SMALLEST VALUE= 18

LARGEST VALUE= 590

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF TSS (mg/l) CATCHMENT : MAUREPAS
SIZE OF SAMPLE= 126 NUMBER OF EVENTS= 174

*	14	0.005	24	0.013	25	0.021	27	0.029	*
*	28	0.036	34	0.044	34	0.052	34	0.060	*
*	38	0.068	38	0.076	39	0.084	40	0.092	*
*	41	0.100	41	0.108	43	0.116	43	0.124	*
*	43	0.132	44	0.139	46	0.147	51	0.155	*
*	52	0.163	52	0.171	54	0.179	54	0.187	*
*	55	0.195	58	0.203	59	0.211	59	0.219	*
*	60	0.227	61	0.235	61	0.242	64	0.250	*
*	65	0.258	66	0.266	68	0.274	68	0.282	*
*	69	0.290	70	0.298	71	0.306	71	0.314	*
*	72	0.322	73	0.330	75	0.338	77	0.345	*
*	77	0.353	78	0.361	81	0.369	81	0.377	*
*	82	0.385	82	0.393	84	0.401	84	0.409	*
*	89	0.417	91	0.425	92	0.433	96	0.441	*
*	97	0.448	97	0.456	98	0.464	99	0.472	*
*	100	0.480	109	0.488	110	0.496	112	0.504	*
*	121	0.512	123	0.520	126	0.528	126	0.536	*
*	126	0.544	127	0.552	129	0.559	131	0.567	*
*	133	0.575	136	0.583	140	0.591	143	0.599	*
*	143	0.607	147	0.615	148	0.623	149	0.631	*
*	151	0.639	152	0.647	153	0.655	158	0.662	*
*	162	0.670	164	0.678	173	0.686	177	0.694	*
*	181	0.702	183	0.710	186	0.718	190	0.726	*
*	195	0.734	196	0.742	198	0.750	200	0.758	*
*	215	0.765	222	0.773	222	0.781	223	0.789	*
*	227	0.797	228	0.805	237	0.813	246	0.821	*
*	256	0.829	258	0.837	263	0.845	268	0.853	*
*	314	0.861	357	0.868	364	0.876	365	0.884	*
*	369	0.892	369	0.900	415	0.908	419	0.916	*
*	450	0.924	476	0.932	478	0.940	502	0.948	*
*	566	0.956	635	0.964	692	0.971	818	0.979	*
*	890	0.987	894	0.995					*

* * STATISTICAL PARAMETERS OF THE SAMPLE *

MEAN= 169.0873
STANDARD DEVIATION= 170.4193
SKEWNESS= 2.313487
COEFFICIENT OF VARIATION= 1.007878
SMALLEST VALUE= 14
LARGEST VALUE= 894

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF BOD5 (mg/l) CATCHMENT : MAUREPAS

SIZE OF SAMPLE= 126 NUMBER OF EVENTS= 174

2	0.005	3	0.013	3	0.021	4	0.029
5	0.036	5	0.044	5	0.052	5	0.060
5	0.068	5	0.076	5	0.084	5	0.092
5	0.100	5	0.108	6	0.116	6	0.124
6	0.132	6	0.139	6	0.147	6	0.155
6	0.163	6	0.171	7	0.179	7	0.187
7	0.195	7	0.203	7	0.211	7	0.219
7	0.227	7	0.235	7	0.242	7	0.250
8	0.258	8	0.266	8	0.274	8	0.282
8	0.290	8	0.298	9	0.306	9	0.314
9	0.322	9	0.330	9	0.338	9	0.345
10	0.353	10	0.361	10	0.369	10	0.377
10	0.385	10	0.393	10	0.401	10	0.409
10	0.417	10	0.425	10	0.433	11	0.441
11	0.448	11	0.456	11	0.464	12	0.472
12	0.480	12	0.488	12	0.496	12	0.504
13	0.512	13	0.520	13	0.528	13	0.536
13	0.544	13	0.552	13	0.559	14	0.567
14	0.575	15	0.583	15	0.591	15	0.599
15	0.607	15	0.615	15	0.623	15	0.631
15	0.639	15	0.647	16	0.655	16	0.662
16	0.670	16	0.678	16	0.686	17	0.694
17	0.702	18	0.710	18	0.718	19	0.726
19	0.734	19	0.742	19	0.750	19	0.758
20	0.765	20	0.773	20	0.781	21	0.789
21	0.797	21	0.805	21	0.813	21	0.821
22	0.829	22	0.837	22	0.845	23	0.853
23	0.861	23	0.868	24	0.876	24	0.884
24	0.892	25	0.900	27	0.908	29	0.916
29	0.924	30	0.932	31	0.940	35	0.948
36	0.956	39	0.964	52	0.971	109	0.979
110	0.987	110	0.995				

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= 16.10317
STANDARD DEVIATION= 16.7554
SKEWNESS= 4.216314
COEFFICIENT OF VARIATION= 1.040503
SMALLEST VALUE= 2
LARGEST VALUE= 110

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF ZINC (mg/l) CATCHMENT : MAUREPAS
SIZE OF SAMPLE= 96 NUMBER OF EVENTS= 173

0.114	0.006	0.129	0.017	0.140	0.027	0.140	0.037
0.140	0.048	0.148	0.058	0.155	0.069	0.160	0.079
0.162	0.089	0.172	0.100	0.173	0.110	0.174	0.121
0.175	0.131	0.183	0.141	0.186	0.152	0.190	0.162
0.192	0.173	0.204	0.183	0.204	0.193	0.207	0.204
0.208	0.214	0.208	0.225	0.213	0.235	0.217	0.245
0.230	0.256	0.230	0.266	0.233	0.277	0.235	0.287
0.237	0.297	0.240	0.308	0.240	0.318	0.246	0.328
0.250	0.339	0.255	0.349	0.257	0.360	0.260	0.370
0.270	0.380	0.270	0.391	0.278	0.401	0.280	0.412
0.284	0.422	0.288	0.432	0.290	0.443	0.300	0.453
0.300	0.464	0.307	0.474	0.307	0.484	0.311	0.495
0.319	0.505	0.323	0.516	0.330	0.526	0.330	0.536
0.332	0.547	0.347	0.557	0.350	0.568	0.352	0.578
0.359	0.588	0.360	0.599	0.361	0.609	0.367	0.620
0.370	0.630	0.375	0.640	0.378	0.651	0.384	0.661
0.384	0.672	0.385	0.682	0.395	0.692	0.402	0.703
0.420	0.713	0.420	0.723	0.449	0.734	0.465	0.744
0.470	0.755	0.470	0.765	0.472	0.775	0.508	0.786
0.511	0.796	0.547	0.807	0.550	0.817	0.570	0.827
0.580	0.838	0.600	0.848	0.650	0.859	0.680	0.869
0.681	0.879	0.693	0.890	0.730	0.900	0.774	0.911
0.815	0.921	0.832	0.931	0.841	0.942	0.890	0.952
0.890	0.963	0.950	0.973	0.959	0.983	1.230	0.994

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= .3796041
STANDARD DEVIATION= .2228809
SKEWNESS= 1.436491
COEFFICIENT OF VARIATION= .5871403
SMALLEST VALUE= .114
LARGEST VALUE= 1.23

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF NO3 (mg/l) CATCHMENT : MAUREPAS
SIZE OF SAMPLE= 87 NUMBER OF EVENTS= 173

*	1.480	0.007	1.600	0.018	1.750	0.030	1.900	0.041	*
*	2.000	0.053	2.160	0.064	2.190	0.076	2.200	0.087	*
*	2.300	0.099	2.310	0.110	2.650	0.122	2.680	0.133	*
*	2.710	0.144	2.810	0.156	2.860	0.167	2.900	0.179	*
*	2.900	0.190	2.910	0.202	3.000	0.213	3.000	0.225	*
*	3.090	0.236	3.090	0.248	3.100	0.259	3.160	0.271	*
*	3.180	0.282	3.200	0.294	3.200	0.305	3.370	0.317	*
*	3.420	0.328	3.450	0.339	3.490	0.351	3.500	0.362	*
*	3.580	0.374	3.660	0.385	3.810	0.397	3.820	0.408	*
*	3.900	0.420	4.010	0.431	4.080	0.443	4.180	0.454	*
*	4.200	0.466	4.260	0.477	4.330	0.489	4.410	0.500	*
*	4.410	0.511	4.600	0.523	4.690	0.534	4.790	0.546	*
*	4.820	0.557	4.970	0.569	5.050	0.580	5.090	0.592	*
*	5.120	0.603	5.280	0.615	5.380	0.626	5.410	0.638	*
*	5.780	0.649	5.800	0.661	5.820	0.672	5.850	0.683	*
*	5.850	0.695	5.900	0.706	6.100	0.718	6.220	0.729	*
*	6.270	0.741	6.580	0.752	6.670	0.764	6.720	0.775	*
*	6.740	0.787	6.840	0.798	6.900	0.810	6.940	0.821	*
*	6.990	0.833	7.150	0.844	7.240	0.856	7.330	0.867	*
*	7.380	0.878	7.870	0.890	8.050	0.901	8.430	0.913	*
*	8.640	0.924	8.700	0.936	9.510	0.947	9.680	0.959	*
*	9.700	0.970	11.600	0.982	14.600	0.993			*

* * STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= 4.934023
STANDARD DEVIATION= 2.394617
SKEWNESS= 1.175709
COEFFICIENT OF VARIATION= .4853275
SMALLEST VALUE= 1.48
LARGEST VALUE= 14.6

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF N-NH4 (mg/l) CATCHMENT : MAUREPAS
SIZE OF SAMPLE= 87 NUMBER OF EVENTS= 173

0.030	0.007	0.060	0.018	0.120	0.030	0.120	0.041
0.170	0.053	0.190	0.064	0.210	0.076	0.210	0.087
0.240	0.099	0.250	0.110	0.250	0.122	0.270	0.133
0.270	0.144	0.270	0.156	0.280	0.167	0.290	0.179
0.290	0.190	0.300	0.202	0.310	0.213	0.320	0.225
0.330	0.236	0.330	0.248	0.350	0.259	0.350	0.271
0.390	0.282	0.410	0.294	0.460	0.305	0.480	0.317
0.490	0.328	0.500	0.339	0.510	0.351	0.510	0.362
0.570	0.374	0.570	0.385	0.570	0.397	0.580	0.408
0.620	0.420	0.640	0.431	0.690	0.443	0.690	0.454
0.690	0.466	0.700	0.477	0.700	0.489	0.770	0.500
0.900	0.511	0.910	0.523	0.910	0.534	0.950	0.546
0.960	0.557	0.970	0.569	0.980	0.580	1.000	0.592
1.010	0.603	1.080	0.615	1.080	0.626	1.090	0.638
1.100	0.649	1.110	0.661	1.190	0.672	1.270	0.683
1.320	0.695	1.320	0.706	1.350	0.718	1.360	0.729
1.410	0.741	1.410	0.752	1.500	0.764	1.500	0.775
1.530	0.787	1.680	0.798	1.720	0.810	1.770	0.821
2.160	0.833	2.180	0.844	2.350	0.856	2.360	0.867
2.400	0.878	2.410	0.890	2.640	0.901	2.660	0.913
2.660	0.924	2.680	0.936	2.920	0.947	3.020	0.959
3.220	0.970	4.550	0.982	5.120	0.993		

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= 1.092644
STANDARD DEVIATION= .9826237
SKEWNESS= 1.680895
COEFFICIENT OF VARIATION= .8993086
SMALLEST VALUE= .03
LARGEST VALUE= 5.12

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF COD (mg/l) CATCHMENT : LES ULIS
SIZE OF SAMPLE= 79 NUMBER OF EVENTS= 98

*	36	0.008	42	0.020	53	0.033	56	0.045	*
*	63	0.058	64	0.071	72	0.083	77	0.096	*
*	87	0.109	88	0.121	92	0.134	92	0.146	*
*	93	0.159	99	0.172	101	0.184	104	0.197	*
*	104	0.210	112	0.222	113	0.235	119	0.247	*
*	120	0.260	121	0.273	123	0.285	129	0.298	*
*	133	0.311	135	0.323	136	0.336	139	0.348	*
*	143	0.361	149	0.374	152	0.386	153	0.399	*
*	159	0.412	169	0.424	172	0.437	173	0.449	*
*	179	0.462	186	0.475	194	0.487	195	0.500	*
*	201	0.513	209	0.525	212	0.538	212	0.551	*
*	216	0.563	221	0.576	224	0.588	229	0.601	*
*	231	0.614	232	0.626	248	0.639	266	0.652	*
*	271	0.664	277	0.677	301	0.689	307	0.702	*
*	308	0.715	320	0.727	320	0.740	338	0.753	*
*	350	0.765	353	0.778	356	0.790	372	0.803	*
*	373	0.816	413	0.828	450	0.841	476	0.854	*
*	565	0.866	701	0.879	730	0.891	749	0.904	*
*	771	0.917	846	0.929	924	0.942	1120	0.955	*
*	1490	0.967	1850	0.980	2720	0.992			*

* * STATISTICAL PARAMETERS OF THE SAMPLE *

* MEAN= 322.519 *
* STANDARD DEVIATION= 411.6557 *
* SKEWNESS= 3.57785 *
* COEFFICIENT OF VARIATION= 1.276377 *
* SMALLEST VALUE= 36 *
* LARGEST VALUE= 2720 *

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF TSS (mg/l)   CATCHMENT : LES ULIS

SIZE OF SAMPLE= 79   NUMBER OF EVENTS= 98

*	40	0.008	44	0.020	88	0.033	92	0.045	*
*	107	0.058	113	0.071	115	0.083	117	0.096	*
*	120	0.109	131	0.121	134	0.134	141	0.146	*
*	146	0.159	146	0.172	150	0.184	158	0.197	*
*	163	0.210	176	0.222	180	0.235	186	0.247	*
*	206	0.260	211	0.273	215	0.285	217	0.298	*
*	225	0.311	226	0.323	228	0.336	234	0.348	*
*	244	0.361	246	0.374	253	0.386	260	0.399	*
*	277	0.412	300	0.424	304	0.437	306	0.449	*
*	307	0.462	312	0.475	329	0.487	353	0.500	*
*	364	0.513	375	0.525	382	0.538	390	0.551	*
*	396	0.563	408	0.576	428	0.588	429	0.601	*
*	438	0.614	443	0.626	445	0.639	457	0.652	*
*	467	0.664	475	0.677	512	0.689	555	0.702	*
*	556	0.715	558	0.727	564	0.740	618	0.753	*
*	662	0.765	745	0.778	778	0.790	790	0.803	*
*	804	0.816	808	0.828	883	0.841	900	0.854	*
*	992	0.866	1010	0.879	1030	0.891	1200	0.904	*
*	1230	0.917	1260	0.929	1400	0.942	1520	0.955	*
*	1660	0.967	1960	0.980	2480	0.992			*

* * STATISTICAL PARAMETERS OF THE SAMPLE *

*

* MEAN= 495.8481 *

* STANDARD DEVIATION= 456.6714 *

* SKEWNESS= 1.97677 *

* COEFFICIENT OF VARIATION= .9209904 *

* SMALLEST VALUE= 40 *

* LARGEST VALUE= 2480 *

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF BOD5 (mg/l) CATCHMENT : LES ULIS

SIZE OF SAMPLE= 79 NUMBER OF EVENTS= 98

6	0.008	9	0.020	10	0.033	11	0.045
13	0.058	14	0.071	15	0.083	15	0.096
16	0.109	17	0.121	17	0.134	18	0.146
18	0.159	19	0.172	19	0.184	20	0.197
20	0.210	20	0.222	21	0.235	22	0.247
22	0.260	22	0.273	23	0.285	24	0.298
24	0.311	25	0.323	26	0.336	26	0.348
26	0.361	27	0.374	28	0.386	28	0.399
29	0.412	29	0.424	30	0.437	32	0.449
33	0.462	34	0.475	34	0.487	35	0.500
35	0.513	35	0.525	35	0.538	35	0.551
37	0.563	38	0.576	40	0.588	41	0.601
44	0.614	45	0.626	45	0.639	48	0.652
49	0.664	50	0.677	52	0.689	56	0.702
60	0.715	60	0.727	68	0.740	68	0.753
73	0.765	75	0.778	79	0.790	79	0.803
104	0.816	109	0.828	112	0.841	126	0.854
127	0.866	130	0.879	131	0.891	134	0.904
159	0.917	186	0.929	234	0.942	273	0.955
327	0.967	465	0.980	666	0.992		

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= 68.44304
STANDARD DEVIATION= 100.397
SKEWNESS= 3.817514
COEFFICIENT OF VARIATION= 1.46687
SMALLEST VALUE= 6
LARGEST VALUE= 666

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF ZINC (mg/l) CATCHMENT : LES ULIS
SIZE OF SAMPLE= 58 NUMBER OF EVENTS= 96

*	0.107	0.010	0.107	0.027	0.124	0.045	0.124	0.062	*
*	0.127	0.079	0.135	0.096	0.138	0.113	0.139	0.131	*
*	0.141	0.148	0.142	0.165	0.147	0.182	0.181	0.199	*
*	0.198	0.216	0.208	0.234	0.208	0.251	0.208	0.268	*
*	0.210	0.285	0.214	0.302	0.229	0.320	0.229	0.337	*
*	0.238	0.354	0.240	0.371	0.244	0.388	0.260	0.405	*
*	0.264	0.423	0.273	0.440	0.290	0.457	0.298	0.474	*
*	0.298	0.491	0.306	0.509	0.311	0.526	0.311	0.543	*
*	0.322	0.560	0.345	0.577	0.356	0.595	0.369	0.612	*
*	0.380	0.629	0.382	0.646	0.396	0.663	0.398	0.680	*
*	0.402	0.698	0.411	0.715	0.451	0.732	0.500	0.749	*
*	0.504	0.766	0.508	0.784	0.527	0.801	0.550	0.818	*
*	0.570	0.835	0.616	0.852	0.730	0.869	0.822	0.887	*
*	1.080	0.904	1.100	0.921	1.100	0.938	1.120	0.955	*
*	1.250	0.973	1.920	0.990					*

* * STATISTICAL PARAMETERS OF THE SAMPLE *

*

* MEAN= .4096208 *
* STANDARD DEVIATION= .341326 *
* SKEWNESS= 2.225345 *
* COEFFICIENT OF VARIATION= .8332731 *
* SMALLEST VALUE= .107 *
* LARGEST VALUE= 1.92 *

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF NO3 (mg/l) CATCHMENT : LES ULIS
SIZE OF SAMPLE= 47 NUMBER OF EVENTS= 96

*	2.430	0.013	2.500	0.034	2.530	0.055	2.880	0.076	*
*	2.880	0.097	3.200	0.119	3.200	0.140	3.250	0.161	*
*	3.380	0.182	3.400	0.203	3.410	0.225	3.470	0.246	*
*	3.670	0.267	3.840	0.288	3.900	0.309	3.930	0.331	*
*	4.130	0.352	4.190	0.373	4.210	0.394	4.230	0.415	*
*	4.240	0.436	4.310	0.458	4.320	0.479	4.360	0.500	*
*	4.360	0.521	4.520	0.542	4.580	0.564	4.700	0.585	*
*	4.780	0.606	4.820	0.627	4.900	0.648	5.000	0.669	*
*	5.190	0.691	5.400	0.712	5.440	0.733	5.540	0.754	*
*	5.610	0.775	5.620	0.797	5.960	0.818	6.200	0.839	*
*	6.510	0.860	6.910	0.881	7.150	0.903	7.830	0.924	*
*	8.530	0.945	11.200	0.966	14.100	0.987			*

* * STATISTICAL PARAMETERS OF THE SAMPLE *
*
* MEAN= 4.908723 *
* STANDARD DEVIATION= 2.135025 *
* SKEWNESS= 2.253652 *
* COEFFICIENT OF VARIATION= .4349452 *
* SMALLEST VALUE= 2.43 *
* LARGEST VALUE= 14.1 *

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF N-NH4 (mg/l) CATCHMENT : LES ULIS
SIZE OF SAMPLE= 47 NUMBER OF EVENTS= 96

*	0.460	0.013	0.480	0.034	0.510	0.055	0.520	0.076	*
*	0.580	0.097	0.640	0.119	0.640	0.140	0.720	0.161	*
*	0.770	0.182	0.770	0.203	0.770	0.225	0.880	0.246	*
*	0.890	0.267	0.890	0.288	1.000	0.309	1.010	0.331	*
*	1.120	0.352	1.210	0.373	1.230	0.394	1.240	0.415	*
*	1.380	0.436	1.390	0.458	1.810	0.479	1.830	0.500	*
*	1.980	0.521	2.050	0.542	2.080	0.564	2.100	0.585	*
*	2.170	0.606	2.210	0.627	2.220	0.648	2.280	0.669	*
*	2.370	0.691	2.460	0.712	2.480	0.733	2.640	0.754	*
*	2.760	0.775	3.220	0.797	3.300	0.818	3.400	0.839	*
*	3.800	0.860	4.000	0.881	4.270	0.903	4.890	0.924	*
*	5.700	0.945	7.120	0.966	7.810	0.987			*

* * STATISTICAL PARAMETERS OF THE SAMPLE *

*

* MEAN= 2.128723 *

* STANDARD DEVIATION= 1.667109 *

* SKEWNESS= 1.606934 *

* COEFFICIENT OF VARIATION= .7831498 *

* SMALLEST VALUE= .46 *

* LARGEST VALUE= 7.81 *

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF COD (mg/l) CATCHMENT : AIX-ZUP
SIZE OF SAMPLE= 52 NUMBER OF EVENTS= 75

41	0.011	46	0.031	46	0.050	54	0.069
58	0.088	58	0.107	67	0.126	73	0.146
76	0.165	83	0.184	87	0.203	92	0.222
95	0.241	102	0.261	108	0.280	115	0.299
116	0.318	130	0.337	133	0.356	134	0.375
134	0.395	138	0.414	140	0.433	141	0.452
156	0.471	158	0.490	160	0.510	177	0.529
198	0.548	217	0.567	244	0.586	250	0.605
253	0.625	269	0.644	276	0.663	281	0.682
320	0.701	359	0.720	364	0.739	370	0.759
408	0.778	409	0.797	454	0.816	500	0.835
503	0.854	515	0.874	614	0.893	652	0.912
695	0.931	760	0.950	803	0.969	1220	0.989

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= 266.3846
STANDARD DEVIATION= 238.6534
SKEWNESS= 1.748656
COEFFICIENT OF VARIATION= .8958979
SMALLEST VALUE= 41
LARGEST VALUE= 1220

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF TSS (mg/l) CATCHMENT : AIX-ZUP
SIZE OF SAMPLE= 52 NUMBER OF EVENTS= 75

22	0.011	54	0.031	56	0.050	59	0.069
65	0.088	68	0.107	68	0.126	79	0.146
98	0.165	103	0.184	111	0.203	112	0.222
114	0.241	130	0.261	137	0.280	139	0.299
140	0.318	147	0.337	170	0.356	170	0.375
182	0.395	186	0.414	188	0.433	190	0.452
195	0.471	198	0.490	207	0.510	222	0.529
222	0.548	233	0.567	235	0.586	239	0.605
245	0.625	259	0.644	282	0.663	295	0.682
306	0.701	319	0.720	388	0.739	389	0.759
437	0.778	449	0.797	570	0.816	595	0.835
612	0.854	702	0.874	757	0.893	804	0.912
860	0.931	960	0.950	976	0.969	2010	0.989

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= 322.1923
STANDARD DEVIATION= 338.8706
SKEWNESS= 2.747618
COEFFICIENT OF VARIATION= 1.051765
SMALLEST VALUE= 22
LARGEST VALUE= 2010

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF BOD5 (mg/l) CATCHMENT : AIX-ZUP
SIZE OF SAMPLE= 45 NUMBER OF EVENTS= 75

1	0.013	1	0.035	3	0.058	5	0.080
5	0.102	5	0.124	8	0.146	9	0.168
10	0.190	11	0.212	11	0.235	11	0.257
13	0.279	13	0.301	16	0.323	16	0.345
21	0.367	25	0.389	27	0.412	28	0.434
29	0.456	30	0.478	32	0.500	36	0.522
41	0.544	42	0.566	44	0.588	47	0.611
47	0.633	49	0.655	49	0.677	54	0.699
54	0.721	55	0.743	64	0.765	74	0.788
85	0.810	103	0.832	123	0.854	127	0.876
127	0.898	127	0.920	153	0.942	256	0.965
460	0.987						

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= 56.6
STANDARD DEVIATION= 78.73286
SKEWNESS= 3.365703
COEFFICIENT OF VARIATION= 1.39104
SMALLEST VALUE= 1
LARGEST VALUE= 460

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF ZINC (mg/l) CATCHMENT : AIX-ZUP
SIZE OF SAMPLE= 41 NUMBER OF EVENTS= 74

0.004	0.015	0.024	0.039	0.025	0.063	0.028	0.087
0.032	0.112	0.040	0.136	0.040	0.160	0.040	0.184
0.040	0.209	0.040	0.233	0.042	0.257	0.045	0.282
0.045	0.306	0.046	0.330	0.050	0.354	0.050	0.379
0.054	0.403	0.060	0.427	0.060	0.451	0.060	0.476
0.062	0.500	0.062	0.524	0.062	0.549	0.066	0.573
0.068	0.597	0.070	0.621	0.070	0.646	0.074	0.670
0.078	0.694	0.080	0.718	0.083	0.743	0.085	0.767
0.086	0.791	0.086	0.816	0.110	0.840	0.120	0.864
0.186	0.888	0.256	0.913	0.260	0.937	0.262	0.961
0.325	0.985						

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= 8.234146E-02
STANDARD DEVIATION= 7.077366E-02
SKEWNESS= 2.07824
COEFFICIENT OF VARIATION= .8595142
SMALLEST VALUE= .004
LARGEST VALUE= .325

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF NO3 (mg/l) CATCHMENT : AIX-ZUP
SIZE OF SAMPLE= 47 NUMBER OF EVENTS= 74

*	0.190	0.013	0.830	0.034	1.180	0.055	1.300	0.076	*
*	1.950	0.097	1.970	0.119	2.170	0.140	2.300	0.161	*
*	2.350	0.182	2.450	0.203	2.640	0.225	2.640	0.246	*
*	2.760	0.267	2.810	0.288	2.840	0.309	2.920	0.331	*
*	2.950	0.352	2.980	0.373	3.060	0.394	3.290	0.415	*
*	3.620	0.436	3.710	0.458	3.800	0.479	3.890	0.500	*
*	4.120	0.521	4.200	0.542	4.300	0.564	4.370	0.585	*
*	4.600	0.606	4.610	0.627	4.660	0.648	4.700	0.669	*
*	5.100	0.691	5.110	0.712	5.220	0.733	5.300	0.754	*
*	5.620	0.775	5.910	0.797	5.930	0.818	5.930	0.839	*
*	6.200	0.860	6.420	0.881	6.430	0.903	7.100	0.924	*
*	10.300	0.945	14.400	0.966	15.000	0.987			*

* * STATISTICAL PARAMETERS OF THE SAMPLE *

* MEAN= 4.385744 *
* STANDARD DEVIATION= 2.850236 *
* SKEWNESS= 2.006229 *
* COEFFICIENT OF VARIATION= .6498867 *
* SMALLEST VALUE= .19 *
* LARGEST VALUE= 15 *

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF N-NH4 (mg/l) CATCHMENT : AIX-ZUP
SIZE OF SAMPLE= 48 NUMBER OF EVENTS= 74

*	0.070	0.012	0.090	0.033	0.100	0.054	0.140	0.075	*
*	0.140	0.095	0.180	0.116	0.180	0.137	0.240	0.158	*
*	0.260	0.178	0.260	0.199	0.300	0.220	0.310	0.241	*
*	0.360	0.261	0.390	0.282	0.410	0.303	0.470	0.324	*
*	0.490	0.344	0.580	0.365	0.630	0.386	0.680	0.407	*
*	0.680	0.427	0.790	0.448	0.820	0.469	0.820	0.490	*
*	0.850	0.510	0.850	0.531	0.940	0.552	1.120	0.573	*
*	1.150	0.593	1.180	0.614	1.200	0.635	1.240	0.656	*
*	1.300	0.676	1.340	0.697	1.390	0.718	1.400	0.739	*
*	1.470	0.759	1.560	0.780	1.620	0.801	1.910	0.822	*
*	2.160	0.842	2.300	0.863	3.300	0.884	4.100	0.905	*
*	4.300	0.925	4.400	0.946	5.200	0.967	6.770	0.988	*
*									*

* * STATISTICAL PARAMETERS OF THE SAMPLE *

* MEAN= 1.300833 *
* STANDARD DEVIATION= 1.441341 *
* SKEWNESS= 2.014632 *
* COEFFICIENT OF VARIATION= 1.108014 *
* SMALLEST VALUE= .07 *
* LARGEST VALUE= 6.77 *

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF COD (mg/l)   CATCHMENT : AIX-NORD
SIZE OF SAMPLE= 50   NUMBER OF EVENTS= 72

48	0.012	62	0.032	63	0.052	65	0.072
71	0.092	77	0.112	86	0.131	86	0.151
92	0.171	106	0.191	108	0.211	120	0.231
120	0.251	121	0.271	127	0.291	130	0.311
155	0.331	156	0.351	157	0.371	173	0.390
178	0.410	185	0.430	188	0.450	194	0.470
199	0.490	204	0.510	208	0.530	211	0.550
217	0.570	220	0.590	240	0.610	274	0.629
349	0.649	359	0.669	361	0.689	371	0.709
396	0.729	416	0.749	428	0.769	487	0.789
512	0.809	547	0.829	566	0.849	583	0.869
608	0.888	630	0.908	668	0.928	860	0.948
1090	0.968	1260	0.988				

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= 302.64
STANDARD DEVIATION= 261.761
SKEWNESS= 1.726541
COEFFICIENT OF VARIATION= .8649253
SMALLEST VALUE= 48
LARGEST VALUE= 1260

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF TSS (mg/l)   CATCHMENT : AIX-NORD
SIZE OF SAMPLE= 50   NUMBER OF EVENTS= 72

29	0.012	29	0.032	47	0.052	52	0.072
58	0.092	60	0.112	62	0.131	83	0.151
95	0.171	113	0.191	113	0.211	116	0.231
117	0.251	124	0.271	125	0.291	127	0.311
172	0.331	174	0.351	176	0.371	211	0.390
216	0.410	218	0.430	245	0.450	256	0.470
264	0.490	290	0.510	295	0.530	305	0.550
313	0.570	319	0.590	331	0.610	340	0.629
370	0.649	374	0.669	376	0.689	396	0.709
400	0.729	409	0.749	418	0.769	444	0.789
481	0.809	492	0.829	567	0.849	586	0.869
660	0.888	858	0.908	860	0.928	1070	0.948
1150	0.968	3780	0.988				

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= 383.32
STANDARD DEVIATION= 547.3538
SKEWNESS= 4.844463
COEFFICIENT OF VARIATION= 1.427929
SMALLEST VALUE= 29
LARGEST VALUE= 3780

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF BOD5 (mg/l) CATCHMENT : AIX-NORD
SIZE OF SAMPLE= 41 NUMBER OF EVENTS= 72

1	0.015	4	0.039	5	0.063	8	0.087
9	0.112	10	0.136	10	0.160	12	0.184
14	0.209	15	0.233	15	0.257	15	0.282
15	0.306	18	0.330	19	0.354	19	0.379
19	0.403	19	0.427	20	0.451	20	0.476
23	0.500	26	0.524	29	0.549	36	0.573
49	0.597	52	0.621	58	0.646	60	0.670
68	0.694	72	0.718	122	0.743	123	0.767
130	0.791	135	0.816	142	0.840	150	0.864
193	0.888	200	0.913	248	0.937	290	0.961
300	0.985						

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= 67.63415
STANDARD DEVIATION= 80.01819
SKEWNESS= 1.522462
COEFFICIENT OF VARIATION= 1.183103
SMALLEST VALUE= 1
LARGEST VALUE= 300

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF ZINC (mg/l) CATCHMENT : AIX-NORD
SIZE OF SAMPLE= 35 NUMBER OF EVENTS= 72

0.036	0.017	0.042	0.045	0.047	0.074	0.050	0.102
0.054	0.131	0.060	0.159	0.060	0.188	0.062	0.216
0.067	0.244	0.067	0.273	0.074	0.301	0.090	0.330
0.090	0.358	0.091	0.386	0.094	0.415	0.100	0.443
0.100	0.472	0.100	0.500	0.102	0.528	0.110	0.557
0.122	0.585	0.140	0.614	0.140	0.642	0.150	0.670
0.150	0.699	0.152	0.727	0.170	0.756	0.172	0.784
0.172	0.813	0.180	0.841	0.214	0.869	0.214	0.898
0.230	0.926	0.260	0.955	0.277	0.983		

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= .1211143
STANDARD DEVIATION= 6.326306E-02
SKEWNESS= .7478201
COEFFICIENT OF VARIATION= .5223419
SMALLEST VALUE= .036
LARGEST VALUE= .277

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF NO3 (mg/l) CATCHMENT : AIX-NORD
SIZE OF SAMPLE= 36 NUMBER OF EVENTS= 72

0.230	0.017	0.380	0.044	1.100	0.072	1.280	0.099
1.500	0.127	1.530	0.155	1.570	0.182	1.780	0.210
1.840	0.238	2.210	0.265	2.400	0.293	2.580	0.320
2.650	0.348	2.790	0.376	2.800	0.403	2.800	0.431
3.000	0.459	3.020	0.486	3.080	0.514	3.100	0.541
3.320	0.569	3.470	0.597	3.570	0.624	3.600	0.652
3.770	0.680	3.800	0.707	3.820	0.735	3.880	0.762
3.970	0.790	4.600	0.818	4.690	0.845	5.380	0.873
5.900	0.901	7.180	0.928	9.920	0.956	15.500	0.983

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= 3.555833
STANDARD DEVIATION= 2.720424
SKEWNESS= 2.611299
COEFFICIENT OF VARIATION= .7650595
SMALLEST VALUE= .23
LARGEST VALUE= 15.5

SAMPLE OF EMCs WITH THEIR CUMULATIVE PROBABILITIES: (rank-2/5)/(N+1/5)

EVENT MEAN CONCENTRATION OF N-NH4 (mg/l) CATCHMENT : AIX-NORD
SIZE OF SAMPLE= 37 NUMBER OF EVENTS= 72

0.020	0.016	0.070	0.043	0.070	0.070	0.070	0.097
0.070	0.124	0.080	0.151	0.100	0.177	0.100	0.204
0.130	0.231	0.150	0.258	0.220	0.285	0.240	0.312
0.260	0.339	0.260	0.366	0.320	0.392	0.320	0.419
0.400	0.446	0.430	0.473	0.490	0.500	0.500	0.527
0.510	0.554	0.520	0.581	0.540	0.608	0.570	0.634
0.600	0.661	0.700	0.688	0.700	0.715	0.720	0.742
0.760	0.769	0.790	0.796	0.970	0.823	1.000	0.849
1.010	0.876	1.010	0.903	1.020	0.930	1.550	0.957
1.560	0.984						

* STATISTICAL PARAMETERS OF THE SAMPLE

MEAN= .508919
STANDARD DEVIATION= .3975791
SKEWNESS= .8998839
COEFFICIENT OF VARIATION= .7812228
SMALLEST VALUE= .02
LARGEST VALUE= 1.56